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METALS & ALLOYS

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The Magazine of Metallurgical Engineering

INCLUDING

CURRENT METALLURGICAL ABSTRACTS

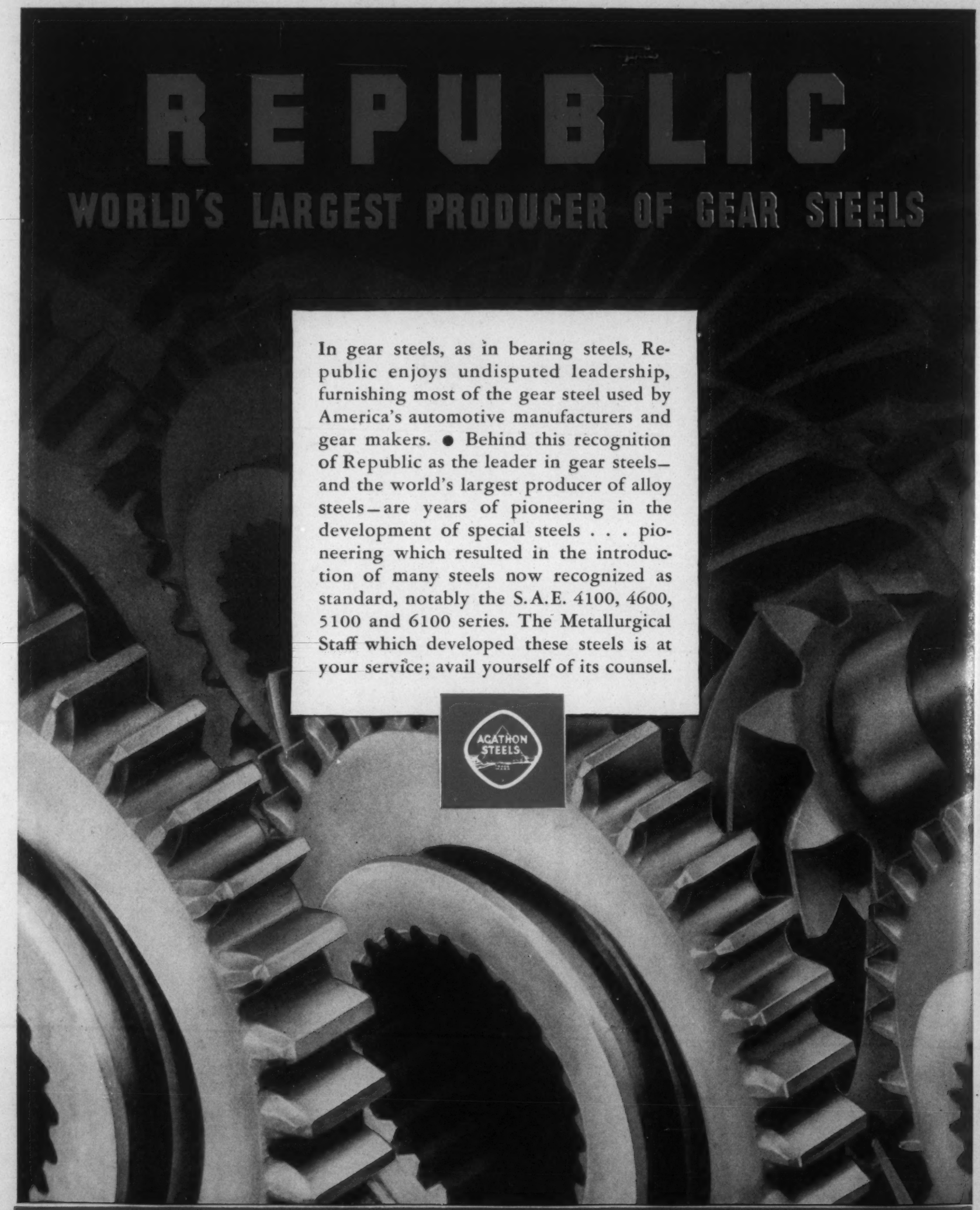
POURING A GOLD MELT AT BRIDGEPORT PLANT OF HANDY & HARMAN

NOVEMBER 1933

VOLUME 4 NUMBER 11

REPUBLIC

WORLD'S LARGEST PRODUCER OF GEAR STEELS



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CURRENT METALLURGICAL ABSTRACTS

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THANKS TO NICKEL

THE BASIC INDUSTRIES ARE GETTING LONGER LIFE FROM EQUIPMENT

NOWHERE is machinery subjected to greater punishment than in wresting raw materials from Nature's vice-like grip. The production of oil, lumber, coal, ores, steel and iron . . . all call for tough, powerful equipment, equipment that stands up under severe conditions of use and abuse.

Time was when no one could tell just how long a machine would last. The buyer installed it and *hoped* for the best. But that was before alloys containing Nickel introduced a new degree of dependability.

Now, thanks to Nickel, alloys of increased dependability are being produced which amazingly add to the life and efficiency of machinery, saving the basic industries millions of dollars every year.

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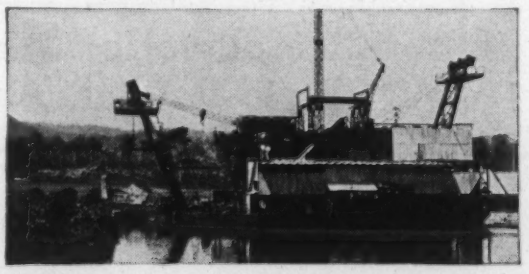
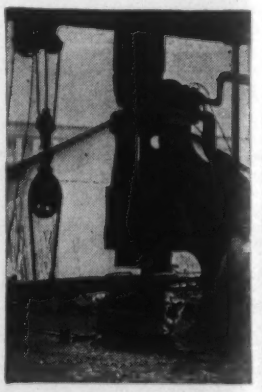
produces a wide range of improved properties that makes these alloys more highly resistant to heat, stress, fatigue, abrasion, corrosion and wear.

Tons and tons of these versatile alloys—Nickel Alloy Steels, Nickel Cast Irons, Nickel Bronzes, Stainless Steels, etc.—are used every year in the basic industries. They are used in the construction of



crushers, drills, power shovels, grinding mills, rolling mills, hoists, mine cars and locomotives, trucks and tractors; in pumps, bearings, gears, shafting, valve and pressure castings and in scores of other applications where greater endurance, increased efficiency and low cost operation and maintenance invariably result. When you consider all the advantages of alloying with Nickel, the extra cost is really small in relation to the benefits secured. In many cases only a little Nickel (from ½% to 5%) is required to produce definitely superior mechanical properties.



Moreover, these alloys containing Nickel are commercially available in all important metal consuming centers *in a variety of compositions*, each carefully established by exhaustive laboratory tests and field service. If you are planning to build new equipment or modernize the old, they will help you to suit it better to modern operating conditions.

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(A NICKEL CAST IRON)

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HIGHLIGHTS

by H. W. GILLETT

Use a Coating of Titanium Nitride to Resist Corrosion

Travers says that a thin film of titanium nitride makes iron resistant to atmospheric corrosion (page MA 345 L7).

Steel Hardening

Tempering for 3000 hours was used in experiments by Müller. His article contains 82 references on the problems of steel hardening (page MA 346 R3).

What Makes Drop Shot Round?

Arsenic doesn't make drop shot round by increasing the surface tension, but rather by the arsenic trioxide fluxing the lead oxide found, according to Tammann and Dreyer (page MA 346 L8).

Transmission Cable with Triangular Cross-Section

According to experiments by Davison, Ingles and Martinoff a transmission cable should have a triangular cross section to cut down vibration and avoid fatigue failure (page MA 350 R2).

Properties of Copper

Properties of copper without oxygen (so-called "oxygen-free, high conductivity") are described by Webster and co-workers (page MA 341 R3). Same tensile strength as tough pitch, higher ductility and ability for deformation. Craig and Klopsch (page MA 342 L4) find that arsenic in phosphorized copper does not lower ductility or workability.

Free-Cutting Brass

Free-cutting brass gets attention in England and the U. S. See Morris (page MA 342 L4) and the account from *Machinery*, London (page MA 342 L6).

Nickel and Silver and Copper

Nickel is not a proper element for alloying with silver in presence of copper, say Guertler and Bergmann (page MA 346 L5).

Deep Drawing Test

Cunningham finds the German "hole-widening" test useful for deep-drawing stock (page MA 361 L6).

DO YOU want to know what metallurgical engineers are saying, the world over? Look in the Current Metallurgical Abstracts. Here are some of the points covered by authors whose articles are abstracted in this issue.

---

47 Varieties

A testing laboratory at Darmstadt, Germany, is reported (Berndt, page MA 365 L5) as having 47 varieties of endurance testing machines.

Welding of Copper

Oodles of information is published about welding of steel and quite a lot about welding aluminum but relatively little about welding copper and its alloys. However, Martin (page MA 355 R1), Nauck (page MA 355 R5), Rietsch (page MA 355 R2), Roberts (page MA 355 L10), Dorat (page MA 355 R10) and an anonymous article or two for good measure deal with copper welding.

Wire Drawing Lubrication

Lubrication in wire drawing is discussed in articles by Francis and by Macon (page MA 361 L7).

Precipitation Hardened Copper Steels

Precipitation hardened copper steels are attractive because of their properties and the simplicity of their heat-treatment says C. S. Smith (page MA 342 R5).

Hard Copper

Cold worked copper has remained hard for 6000 years says Carpenter (page MA 364 L4).

Heredity and Pig Irons

Piwowarsky and Nipper could detect no definite "hereditary properties" in different pig irons, though they do not deny the possibility of heredity (page MA 342 R4).

Rolling Cast Iron

Cast iron can be hot-rolled to 1 mm. starting with 12 mm. plates, according to *Verkehrstechnik* (page MA 352 L3). Such sheet can be rolled onto steel, it is stated. See also Nipper (page MA 359 L10).

We Would Expect This to be the Case

Iron ore shipments decreased 81% in 1932, says Davis (page MA 364 R3). What a lot that short statement tells!

Removing Corrosion Products

According to Finnegan and Corey, corrosion products can best be removed from iron in corrosion testing by use of caustic soda and zinc (page MA 362 L1).

Stainless Invar

Honda announces a "Stainless Invar" (page MA 342 R9).

Martensite and Cementite

Carbon separated from martensite on tempering stays free until 200° C. is reached, before forming cementite, according to Wever and Naeser (page MA 346 R6).

Machining Alloys

Becker (page MA 360 R1) discusses carbides, nitrides and borides of Ti, Zr, etc. And *Machinery*, London, mentions a new Mo-Ti carbide tool (page MA 360 R5).

What is a Good Finish on a Roll?

Machinery, London (page MA 359 L2), raises the point that a quantitative evaluation of what is meant by a "good finish" on a roll, is sadly needed.

Old Rails Still Good

Fifty-year-old rails are still carrying traffic in England, according to Inglis (page MA 342 R9).

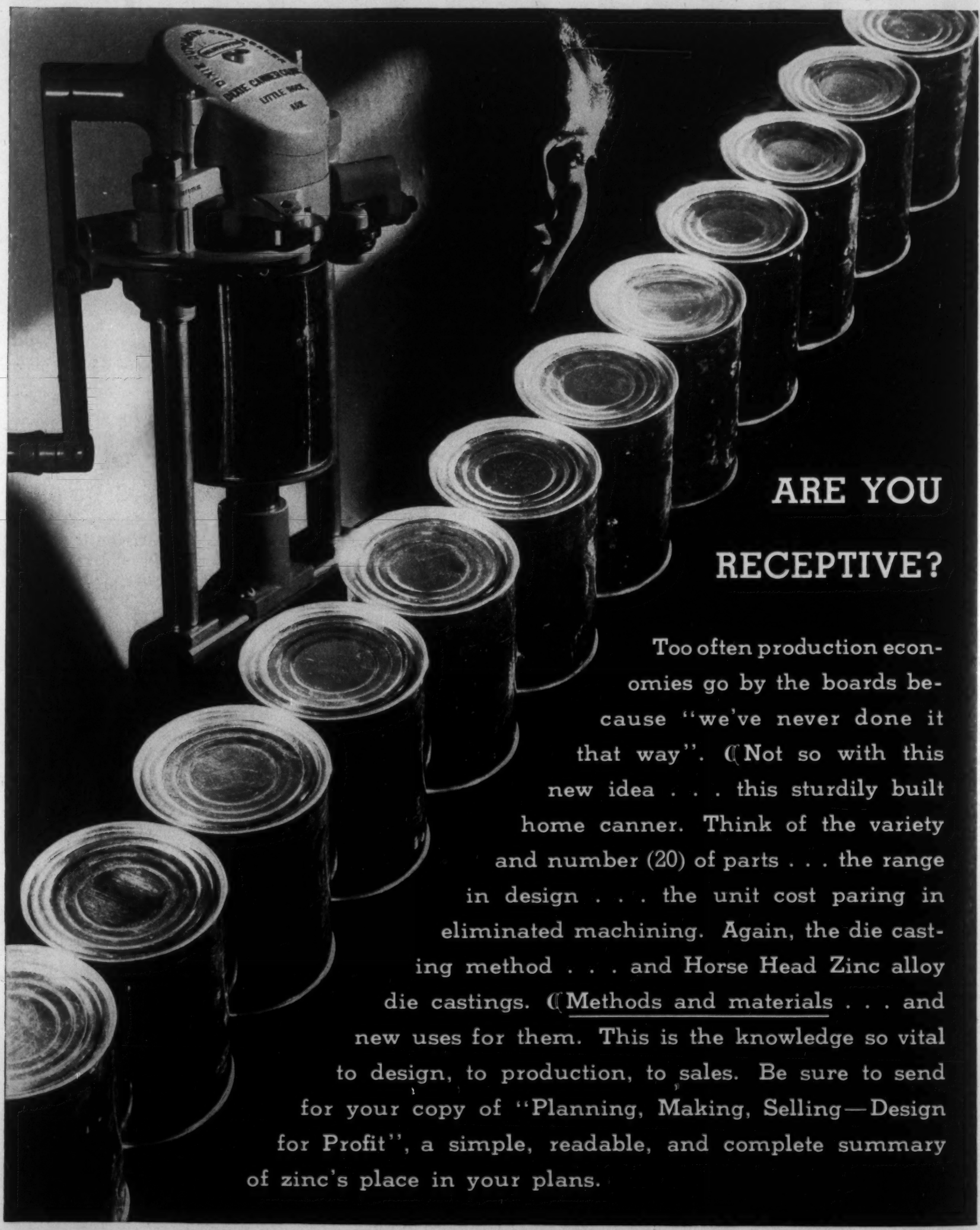
Solders

According to the Bell Telephone Laboratories (Baillard, page MA 354 R1) 9% of Cd in a wiping solder allows cutting the Sn from 38% down to 24%, while another author (Anon, *Machinery*, page MA 354 R2) says that Cd plated surfaces are more readily soldered than tinned ones.

Tube Welding

The Kaiser Wilhelm Institut für Eisenforschung (Wallman & Pomp, page MA 355 L4) has made a comprehensive study of different methods of welding in relation to tube manufacture.

HORSE HEAD 99.99+% UNIFORM QUALITY ZINC



ARE YOU RECEPTIVE?

Too often production economies go by the boards because "we've never done it that way". ((Not so with this new idea . . . this sturdily built home canner. Think of the variety and number (20) of parts . . . the range in design . . . the unit cost paring in eliminated machining. Again, the die casting method . . . and Horse Head Zinc alloy die castings. ((Methods and materials . . . and new uses for them. This is the knowledge so vital to design, to production, to sales. Be sure to send for your copy of "Planning, Making, Selling—Design for Profit", a simple, readable, and complete summary of zinc's place in your plans.

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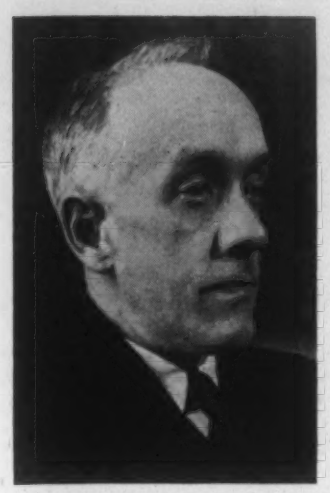


Editorial Comment

Statistical Methods

SOME of our readers have suggested that statistical methods of evaluating variables are deserving of editorial comment. We freely admit that we haven't the mathematical ability to deal with this in an erudite fashion. If we had, and did, few readers would go with us beyond the opening paragraph any way, so let's take it from a layman's point of view.

It used to be fashionable among high-brow research men, to apply least squares to a plot of data consisting of say a dozen points, so that the curve would "truly represent" the data, forgetting that a thirteenth observation would be likely to shift the position of the line quite as much as the difference between its position when located by eye and that by the least square method. A saner point of view is appearing, and few people now strain at the gnat of least squares when swallowing the camel of too few observations. Perhaps the main usefulness of the least square method is that two people, working up the same set of data, plot the curve the same, whether the curve really represents the facts or not.

When a really large number of observations are available, statistical methods are very helpful. The span of life of an individual is an entirely unknown quantity. One may live to be 90 or he may be wiped out in an automobile accident today. The life expectancy of a large group of people, however, can be predicted with extreme precision. All life insurance premiums are based on exact actuarial calculations. In other words, when enough units are considered the laws of chance are very exact laws.

Suppose we have a specification for maximum and minimum tensile strength of a given grade of steel, test 1,000 specimens and plot vertically the number of specimens that show a given strength, while we plot the strength horizontally.

A curve results that looks something like the eye of a hook and eye, with the hump at about the average tensile strength, the curve tapering off at each end. Whether the peak in the curve is very sharp or very flat, will give a pretty good idea whether, with a given degree of control, one could or could not meet a more stringent specification. Moreover, if the curve is symmetrical, it carries a presumption, though not absolute certainty, that the deviations are really due to chance and that no systematic variable of importance is exerting an influence.

If the curve has a couple of peaks instead of one, or if it is lopsided or skewed, then some variables are involved that might perhaps be controlled to advantage. In such a case, one can utilize the methods used in Census recording, by which it is possible to tell, by punching cards to show the entries and running them through a tabulating machine, how many one-legged Irishmen from 37 to 47 years old, living in Pennsylvania, are divorced within 17 months of marriage, provided the Census-taker has recorded these data. If the proper variables are recorded, the machine can turn out a set of figures which when plotted, will indicate, in our tensile-strength example, for instance, how the tensile strength was affected by some variable such as carbon or manganese content.

Many firms use such tabulating machines for other purposes, such as making records of what parts went into equipment shipped to a given customer so that it may be possible to trace complaints back and connect up the material and workmanship of the part with its service behavior. So the metallurgist may not have to ask for the purchase of such machines, but may be able to borrow them.

When one has a complex set of variables whose interrelation is not clear when studied by other methods, the statistical methods of plotting may pick out relations quite clearly that would hardly be guessed at otherwise, and may indicate things that ought to be controlled that have hitherto been left to chance. It is also possible to tell something about whether or not it will pay to control a variable more closely, as for example in reducing the tolerance of a fit among interchangeable parts. There is a story of an electric motor that refused to run on assembly, but when torn down, it was found that every part was within the proper size tolerance. By chance every mating part happened to be at the extreme size in opposite directions. Statistical study of the individual parts will show how often this mismating would be likely to occur. Obviously, it is cheaper to have one machine out of a few thousand that binds and has to be disassembled and the parts thrown back into stock, than to cut down the tolerance on each part to a degree that vastly increases the cost of machining. One might expect the tolerance distribution curve to be "skewed" due to the effect of wear on the tools, and such data might conceivably be used to evaluate tool quality.

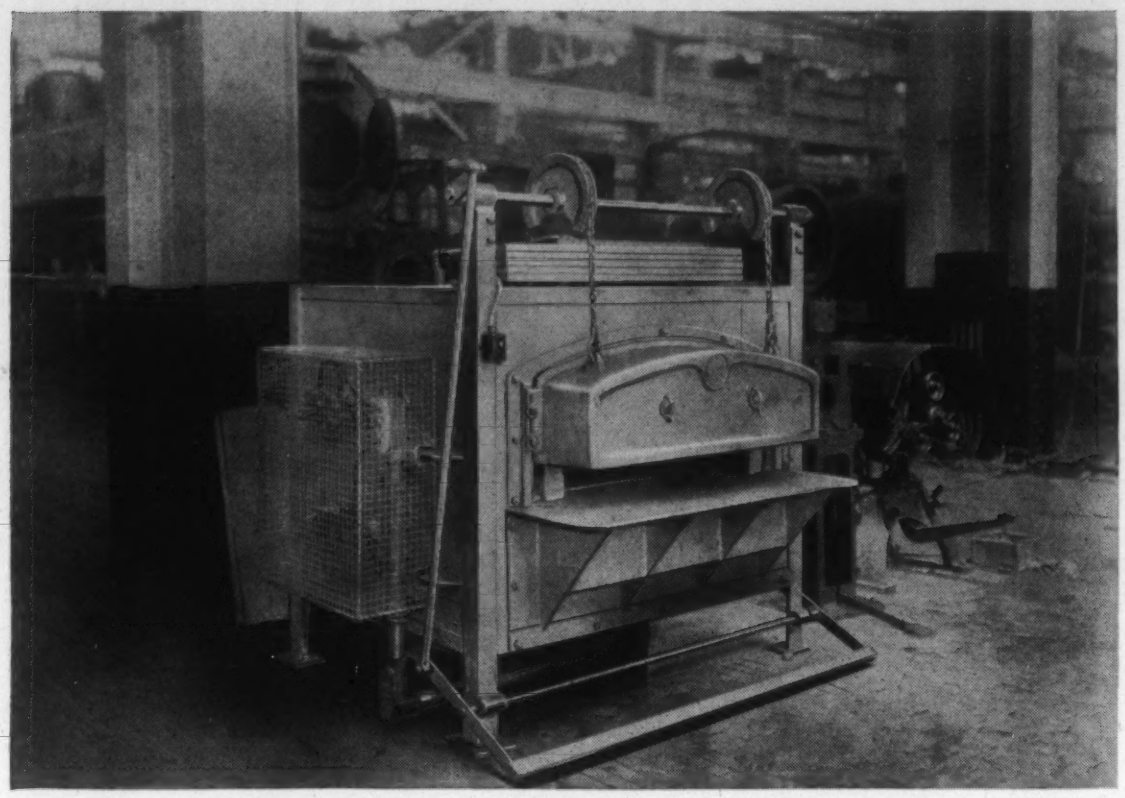
Within limits, it is possible to throw some light on how large a sample need be taken or how many tests need be made to get test results representative of the material sampled, by statistical study of the problem. Merely plotting data as distribution curves will often show so clearly that too few data have been collected for the results to be representative, and thus may keep the observer from going off half-cocked.

Funny-looking curves will set one to thinking about variables he has been neglecting, and the whole statistical method of attack is perhaps most helpful for the point of view it engenders.

Statistical methods are mathematical methods, and like all mathematics, they yield common sense results only when common sense is exercised in picking out the right things to feed into the mathematical machine. Like all specialties, its disciples have a jargon of their own and they are likely to make it sound far more mystifying than

(Continued on Page 169)

"Q. E. D." on Electric Forging—



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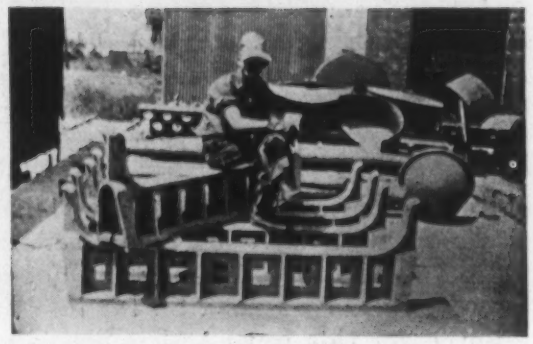
High-Chromium Iron Alloys for Castings

by W. F. Furman*

THE first part of this paper appeared in the October issue, page 147. As this paper is confined to a description of high chrome-iron castings, alloys containing appreciable amounts of alloying elements other than chromium will not be included. However, various other elements, in comparatively small proportions, are sometimes added to the straight chrome-iron castings, to impart certain desirable qualities. The essential characteristics of the chrome-iron castings are not materially changed by such additions, so the effect of these various alloying elements will be covered in this issue.



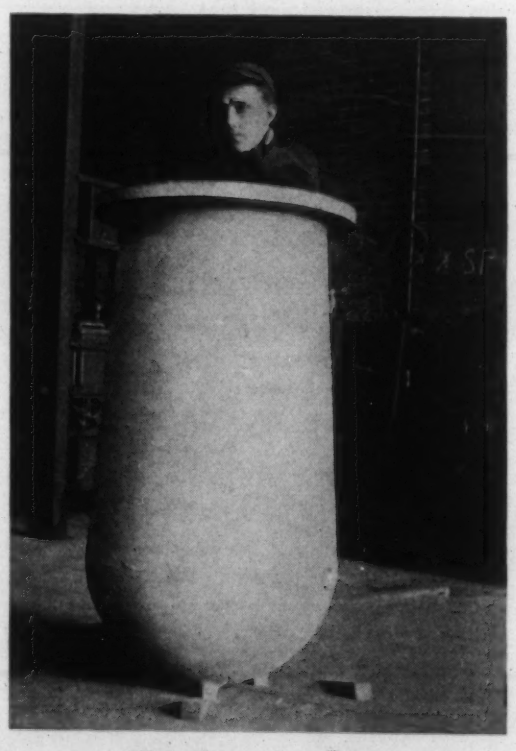
Chrome Iron Furnace Bucks

Nickel

There are many alloys on the market which contain considerable quantities of nickel and chromium in various combinations, such as 60.00% nickel, 20.00% chromium; 35.00% nickel, 15.00% chromium; 25.00% chromium, 20.00% nickel; 24.00% chromium, 12.00% nickel; and 18.00% chromium, 8.00% nickel. Description of such alloys is outside the scope of this paper. However, there are times when the addition of nickel in small quantities, say 2.00 to 3.00%, to straight chrome-iron castings, is desirable.

It is well known that nickel in appreciable quantities adds considerably to strength at high temperatures. The chrome-nickel and nickel-chrome alloys can carry much heavier loads and are less apt to warp and crack at high temperatures than the straight chrome-irons. However, nickel is a decided disadvantage in installations where sulphur gases are present, so that oftentimes the designer has to decide whether to sacrifice strength for corrosion resistance or vice versa.

Sometimes the solution is found by adding 2 or 3% nickel to an alloy containing 28.00-30.00% chromium. Such an addition tends to produce a finer, denser grain, adds some ductility and increases strength at high temperatures to some extent. This is not enough nickel to cause trouble from sulphur attack. In fact, the claim has been made that danger from sulphur gases is eliminated if chromium is present in the ratio of 2 parts to 1 part of nickel. The experience of the writer does not substantiate this claim in the sense that it is by any means a universal rule. Where sulphur conditions are not very bad, it is fairly safe, but given any appreciable amount of sulphur gases, at fairly high temperatures more than 3 or 4% nickel is apt to cause trouble.



High Chrome Iron Retort

While the addition of nickel in small amounts to chrome-iron castings has some advantages, it also has disadvantages. The straight 27.00-30.00% chrome-iron castings are easily machined but the addition of 2.00-3.00% nickel toughens them considerably and makes machining operations rather difficult. In fact, this particular percentage of nickel in castings makes them harder to machine than castings containing larger amounts of nickel. In some instances, even these small nickel additions have a bad effect on corrosion resistance. This is true, for example, of castings used with a mixed nitric and sulphuric acid solution. Straight 27.00-30.00% chrome-iron castings give very satisfactory service under such conditions, but with as little as 1.00% nickel added to this composition, failure from acid attack is fairly rapid.

Small amounts of nickel are sometimes added to the high carbon, high chrome-iron castings, which are intended primarily for abrasion resistance. Ductility is increased to some extent by such additions, but the very fact that castings are tougher, means that abrasion resistance is somewhat lowered. On the other hand, shock resistance is increased, which sometimes compensates for the lower abrasion resistance.

*Vice-President, The Duraloy Co.

Miscellaneous 17-20% Chromium Castings
Courtesy, Lebanon Steel Foundry)

Manganese

Chrome-iron castings contain usually about 0.50% manganese, the exact amount depending somewhat on melting conditions. Some heats have been made with as

much as 10.00-12.00% manganese added to about 24.00% chromium. Such castings have certain advantages. The manganese adds strength at high temperatures, without being susceptible to sulphur attack. In actual service, disadvantages developed. It was found that grain growth was greater than in the castings of the straight chrome-irons, although oxidation and corrosion resistance was about the same. There are interesting possibilities in such an alloy which may be developed later.

Molybdenum

Molybdenum added to 18.00% chrome, 8.00% nickel castings, in quantities up to about 4.00% materially increases resistance to sulphuric and sulphurous acids, such as are encountered in sulphite pulp mills. It seems to have somewhat the same effect when added to the 27.00-30.00% chrome-irons. An alloy of about 28.00% chromium, with 1.50-3.00% molybdenum and low carbon is reported to have excellent service in sulphite pulp mills and has the advantage of not being susceptible to intergranular corrosion. So far its commercial use in this country for this purpose has been limited.

Small molybdenum additions tend to increase the tensile strength of castings but this does not seem to be effective at temperatures over about 1500° F. In fact, molybdenum seems to cause a certain amount of disintegration at these higher temperatures.

at least as resistant to corrosion as similar castings with no nitrogen, is sufficient for practical purposes. Results against nitric acid, compared to a test piece of the same analysis, except without nitrogen, are shown in Table 3.

Table 3

	1st 48 hour period	*2nd 48 hour period*
SAMPLE A	.0051	.0110
SAMPLE B	.0153	.0368

Samples immersed in 65.00% boiling Nitric Acid for periods indicated.
Results expressed in inches penetration per month.

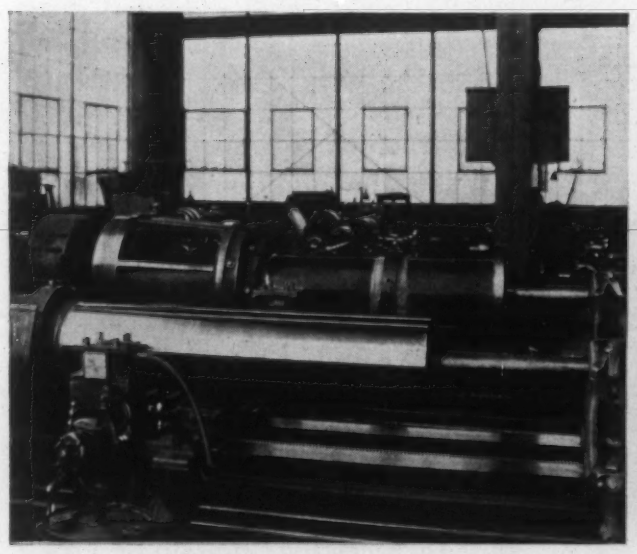
	Analysis of Samples	
	Sample A	*Sample B*
Chromium	24.43	25.08
Carbon	0.35	0.35
Nickel	1.20	1.18
Nitrogen	0.28	0.06

Physical tests were made of castings from a heat containing 24.85% chromium, 0.35% carbon, 1.15% nickel, 0.28% nitrogen. These results were secured:

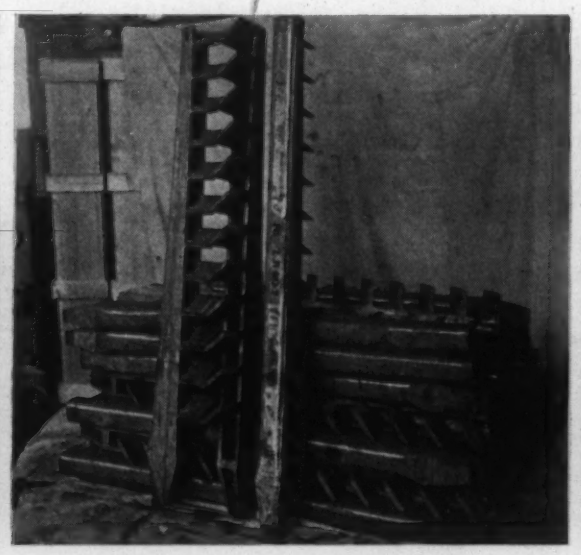
Tensile strength	96,500 lbs./in.^{2}
Elastic limit	75,600 lbs./in.^{2}
Elongation in 2 inches	3%
Brinell hardness	240

After a simple heat treatment the ultimate tensile strength was increased to 103,000 lbs. and elongation to 4%. The elastic limit was decreased to 62,000 lbs. These results compare with typical results of castings of a similar analysis without nitrogen as follows:

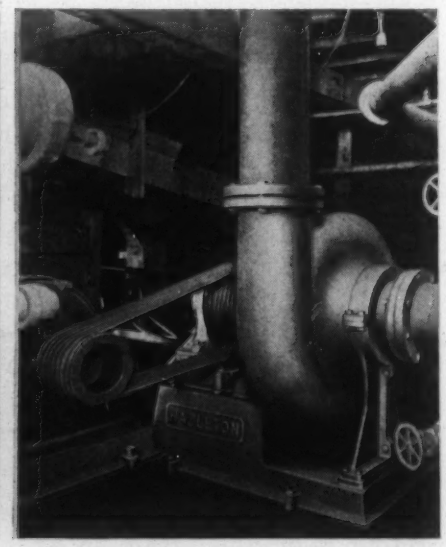
Tensile strength	68,000 lbs./in.^{2}
Elastic limit	50,000 lbs./in.^{2}
Elongation in 2 inches	0%



Centrifugally Cast Chrome-Iron Polished Roll
(Courtesy, Shenango-Penn Mold Co.)



Chrome-Iron Rabble Arms



High Chrome-Iron Sand Pump
(Courtesy, Barrett-Haentjens Co.)

Tungsten

Tungsten additions also tend to increase the physical properties of chrome-iron castings but here again such additions are not usually effective above about 1600° F.

Titanium

Titanium additions to the chrome-nickel alloys are effective in preventing intergranular corrosion. While their effect on chrome-iron castings has not been so well determined, there seems to be some tendency to a slight increase in grain size, which is not advantageous.

Nitrogen

Small percentages of nitrogen (under 1.00%) added in the form of high nitrogen ferro-chromium have a remarkable effect on chrome-iron castings in refining the grain, and increasing ductility and strength. So far as can be determined in laboratory tests, corrosion resistance is not decreased. In fact, it appears to be slightly improved, possibly because of the grain refinement caused by the nitrogen. However, the nitrogen is not added to improve corrosion resistance and the apparent certainty that nitrogen bearing chrome-iron castings are

There is some tendency for the nitrogen bearing castings to contain gas pockets but it seems to be possible to overcome this by taking proper precautions in melting. The advantage of greater physical strength, a denser grain and particularly greater ductility is obvious. It is entirely possible that the use of nitrogen in the chrome-iron castings may greatly extend their field of usefulness.

As would be supposed, the melting and casting of chrome-iron presents peculiar difficulties. Often a considerable change in foundry technique is required for a slight change in analysis. The higher the carbon, within the ranges discussed, the more fluid the mixture coming from the furnace, so that the close temperature restrictions which apply to the low carbon alloys are not so important. The low carbon heats are very sluggish and can only be poured successfully into the molds when fairly hot. However, as already indicated, the pouring temperature has a direct influence on grain size, that is, the higher the pouring temperature, the larger the grain size in the casting. Consequently, it is necessary to pour on the cold side to insure as small a grain as possible and yet have the heat hot enough to flow. This means a narrow temperature range for pouring. Molds have to be prepared

with great care and there are many other factors which have a decided effect on the quality of castings produced. It will be understood from this that castings of identical analysis produced in different foundries will vary considerably in their characteristics, because of a difference in foundry methods.

It is necessary to segregate scrap very carefully, so that the melter, in making up his charge, can estimate accurately what the final analysis of the heat will be. Unless there is absolutely no doubt as to the analysis of any scrap bought outside, it should be pigged and a complete analysis of the pig heat made before any of it is added to a charge. This same rule applies to shop scrap, the exact analysis of which is, for any reason, uncertain.

Each heat should, of course, be analyzed and, so far as possible, a record kept of the castings produced in the heat. This record should be extended to include results secured by castings in actual service. Only an accumulation of such information over a period of years can determine exactly the proper alloy to be recommended for a specific application. Those making such recommendations should be careful not to become dogmatic and to assume too much from insufficient information. Not until a number of installations under the same service conditions have been observed for several years is it safe to come to definite conclusions. Even then, a very slight change in operating conditions may completely alter the situation and require the use of a different alloy. Information contained in this paper is based on 10 years' experience in the production of chrome-iron castings and every effort has been made to keep it accurate and in accord with results secured in actual service. Even so, it is realized that it will be many years before the last word regarding such alloys can be written.

EDITORIAL COMMENT

(Continued from Page A 11)

it need be. Instead of using the physical chemist's term "system" for the bunch of things we are dealing with in a given case, they call it the "universe." We find such phrases as "If the regression of y on x is linear and the scatter of points is homoscedastic" then something or other happens, in a standard book on the subject.

Some mathematicians think that much in statistical theory as now generally used is based on unsound premises, and a mathematically-minded friend tells us that probably half of the attempts made to use statistical methods, use them wrongly. Nevertheless, it is plain even to the layman that we have made more progress even with some misuse of the methods than we would have without any such methods. What is needed is for some low-brow who has used the methods to advantage in the simpler, correct and satisfactory modes of application, to point out how and where they have fitted in. It seems to us to bear much the same relationship to metallurgy that X-ray crystal structure work does. Both are tools for the metallurgist, relatively new, and in themselves so fascinating to certain types of minds that they get more interested in the tool itself than in its application.

The present-day type of physicist makes X-ray crystal structure so complicated that it scares off the common or garden type of metallurgist, and the mathematician is making statistical methods appear more formidable than they are.

When both of these get shaken down into the position in metallurgy that microscopic examination now holds, they will all be classed as useful tools, all having limitations, and all requiring common sense and judgment in knowing how far to carry them, and how much weight to give their indications.

In discussion of this matter, Dr. John Johnston remarked that it is essential that the subject be kept simple so that the method may be used by the man in the works himself—as it must be for the greatest success; it is much less likely to succeed in the hands of a statistical department, unacquainted with details of everyday operation.

The statistical methods seem especially powerful for the works metallurgist, who wants to know what are the effects of small variables upon the quality and uniformity of his regular product, or what the variables are that are not recognized as such. He has available thousands of articles that are being inspected and tested before shipment. If he can list the known and suspected variables and get those recorded in regular production, feed all the data through the tabulating machines, and plot the results in statistical curves, he is likely to get a pretty good inkling of what variable is producing what result.

Then the research laboratory can take up the problem, and outline a short series of experiments in which all other variables are rigorously kept constant, and the one in question varied, which will give a direct measure of its effect.

In general, statistical methods are not so helpful for the research laboratory, since it cannot afford to make thousands of articles in order to get a big enough "universe."

It does not have the production equipment nor can it normally dispose of the good products made. It may now and then, in an extraordinarily extensive investigation, be able to apply the methods, but in general, it can more effectively confine itself to subdividing the problem into its component parts, segregating the variables and making a few carefully chosen and controlled experiments on each variable.

The production plant and the routine laboratory, with piles of data, but little opportunity to juggle variables for fear of disturbing production, can sometimes apply statistical methods in its inquiry into how the variables are changing due to accidental causes and what results such changes bring. It is regrettable that those who are applying the methods seldom describe what they are doing and what results they are obtaining thereby.

Probably the simplest and clearest idea of the "practical application of statistical methods" is found, in German, in a book with that title[1] recently issued from the pen of Daeves, of the Vereinigte Stahlwerke, Düsseldorf.

It would be the best introduction to the subject we know of for any type of reader, and is especially good for the metallurgist to start his study with since the author draws largely for his examples on his own data accumulated in actual steel-works application of the methods.

With the appreciation of the everyday utility and good horse sense of the simpler modes of statistical approach that this will give, the student can later progress more intelligently to more complicated mathematical methods of attack should he deem it worth while. At any rate, some inoculation with statistical ideas will be worth while for the mere purpose of keeping oneself from drawing too sweeping conclusions from meager data.—H. W. GILLETT

[1]Praktische Grosszahl-Forschung. K. Daeves, 132 pages, 58 figures, V.D.I. Verlag, Berlin, 1933.

Fatigue and the
Hardening of Steels

by H. J. French*

Extended Abstract by H. W. Gillett

IT HAPPENS that subjects dealt with by both the Marburg lecturer before the American Society for Testing Materials this summer, Dr. H. T. Gough, and the Campbell lecturer before the American Society for Steel Treating this fall, Mr. H. J. French, relate to problems of fatigue of metals.

While engineers commonly consider that the endurance of a steel rises proportionately as the strength and hardness rise, this linear proportionality fails somewhere around 450 Brinell, and the curve shows a peak so that in general, a hardened but untempered steel has a distinctly lower endurance limit than if it has been tempered so that its hardness and strength just begin to be reduced. This is of distinct importance in springs, battering tools and the like.

There is also a general idea among engineers, which is a close approximation to the truth in steels considerably softened by tempering, that when given the same strength, by heat-treatment, different alloy steels show about the same endurance properties and service behavior, especially if their impact properties are similar also. This ceases to be the case at very high hardnesses, and different alloy steels act as quite different entities.

After noting the interesting fact that in the high hardness ranges delayed fracture may occur in a specimen that has run 10 million cycles unbroken—a number sufficient to establish the endurance limit of softer steels—so that much longer runs are required to establish the endurance limit of a very hard steel, French discusses possible reasons for the differences in endurance properties of quenched, untempered or but slightly tempered steels.

He notes that the performance of water-quenched, untempered, high-carbon, plain carbon steels under repeated stress is poor (endurance limit down to about 75,000 lbs./in.^{2}), while that of some alloy steels hardened by oil quenching is much better (around 90,000 lbs./in.^{2} or more), and deduces that the retained austenite in the latter has a beneficial effect. This explanation is made plausible by determinations of retained austenite by magnetic methods, by liquid air treatment, etc., which produced data consistent with the idea that the softer, more deformable austenite has a cushioning effect during the quenching operation with its resultant change of volume and creation of internal stress. However, a low carbon martensite did not require to be accompanied by noteworthy amounts of austenite to give rather good endurance properties, though even this was improved by moderate tempering.

Since the phenomenon of delayed fracture was met, in order to make sure that a bar that had not fractured in say 10 to 25 million cycles had not been damaged so that it would break later (and fractures were met at as high as 59 million cycles), such bars were re-tested at a higher stress and their life at the higher stress compared with the normal life for a bar run initially at that higher stress. A shorter life indicated damage, a longer one, improvement.

The phenomenon of strengthening by understressing (stressing below the endurance limit) is well known, but it is generally considered that stressing above the endurance limit produces damage. Yet it is well known that almost any steel will stand a few cycles of repeated stress above, but not too far above, the endurance limit, without damage.

Since the ability to stand occasional overstress is a decided virtue in a spring or battering tool, the ability of the different steels to stand overstress was studied. The bars were run for various numbers of cycles at various stresses above the endurance limit and after that preliminary treatment were again run at the previously determined endurance limit for virgin bars. If they broke in, say, less than 10 million cycles, they were shown to be damaged by the previous overstress, while if they acted just like a virgin bar in spite of the overstress, they were undamaged. By making a series of such tests, a "damage line" could be drawn on the S-N diagram, dividing the area between the stress axis and the upper part of the S-N curve into a safe and an unsafe area. The damage line runs into the S-N curve at the endurance limit and, in general, reflects the shape of the upper part of the S-N curve.

Differences in the ability of hard steels to stand punishment by stressing above the endurance limit are very clearly brought out by the damage lines. The benefit of tempering a water-quenched, high-carbon, plain-carbon steel is even more strikingly brought out by the damage line curves than by mere consideration of the endurance limits after different tempering treatments. Release of internal stress is the most probable explanation of the benefit of tempering.

In applying the damage line method of study to some special steels, very interesting results were obtained. While quenched (martensitized) and tempered alloy steels showed a large area of no damage, two age-hardening steels, one of 0.53 C, 0.54 Mn, 3.52 Ni, 1.66 Al, 0.11 Cr and one of 0.58 C, 0.73 Mn, 2.0 Si and 1.27 Cu were found to give almost no area of no-damage. They would stand hardly any over-stress above the endurance limit although the endurance limits themselves were about what would have been expected from the strengths and hardnesses of the steels.

Even more interesting was the peculiar behavior of an induction furnace heat of nickel silicon steel, of 0.49 C, 0.83 Mn, 3.02 Ni, 1.65 Si. When oil quenched from 1575°F. and tempered at 1200°F., it showed a decidedly high endurance limit for its strength (endurance ratio over 60% for specimens water quenched after tempering), but had little ability to stand overstressing. But when tested either not tempered at all or after tempering at 675°F., it was found to be actually *improved* by overstressing. Indeed, the tempered material, which on virgin bars had an endurance limit of 100,000 lbs./in.^{2}, had a series of bars severely overstressed (25,000 to 50,000 cycles at 125,000 to 150,000 lbs./in.^{2}) and the endurance limit was then determined on this series, just as if they were a set of ordinary virgin bars, and the endurance limit was 110,000 lbs./in.^{2}.

Another lot of similar steel, 0.45 C, 0.80 Mn, 3.01 Ni, 1.60 Si, but made in an arc furnace, was tested after the 1575° oil quench, 675°F. draw, and found not to be benefited by overstressing; in fact, the "no damage" area was small, and analogous to that found on the precipitation hardened Ni Al and Cu Si steels. But, the virgin endurance limit of the steel was clear up to 120,000 lbs./in.^{2}, i.e., higher than that of the induction heat after overstressing.

From these observations, it was postulated that the Ni Si steel also had age-hardening properties, and that in the induction furnace heat after the 1200° draw, the age-hardening precipitation had occurred, while in untempered and 675° draw specimens the precipitation was brought about by repeated overstress. In the arc furnace heat, the precipitation must have occurred during the 675° draw.

That the Ni Si steels were peculiar in another way was shown by the fact that both were temper brittle, but of different degrees of temper brittleness, and it is postulated that temper brittleness is a manifestation of a precipitation hardening phenomena.

Static overstress tests were made on several Ni Si steels of this class and the results seem to be consistent with the postulates made as a result of the endurance tests. It is suggested that temper brittleness, long considered as a "characteristic without virtue," may perhaps have some assets.

The lecture opens up many useful lines of thought especially applicable to the problem of getting maximum, or rather, the optimum combination of hardness, yield and tensile strength, endurance limit and ability to stand overstress, in springs, battering tools and the like.

Alloying and quenching so as to produce a suitable amount of austenite, tempering to relieve internal stress, appraisal of ability to stand overstress by the "damage line" method, and utilization of the good endurance properties and avoidance of the bad ones resulting from precipitation hardening, are all points of view either quite new or hitherto too slightly understood and too little emphasized, that are brought out in this noteworthy contribution of French.

*International Nickel Company.

The Forgeability of High-speed Steel

by O. W. Ellis* and J. Barbeau**

In previous papers[1] the senior author has shown how carbon and other elements affect the forgeability of iron. However, in none of the alloys hitherto investigated have the metallic elements other than Fe exceeded 3.5%, nor the C 0.9%.

Through the courtesy of H. B. Allen, chief metallurgist of Henry Disston and Sons, Inc., the authors were supplied with 2 bars of high-speed steel which had been forged from a billet of the following analysis:

Carbon	.70%
Manganese	.27%
Phosphorus	.020%
Sulphur	.013%
Silicon	.28%
Nickel	.10%
Chromium	3.69%
Tungsten	19.23%
Vanadium	1 12%

These bars were ¾ inch and 1 inch in diameter, respectively. Most of the work described below was carried out on the ¾-inch material, from which sufficient normal samples (samples of which the heights and diameters were equal) were machined to enable a very complete survey to be made of the forgeability-temperature relationship for this steel.

This is not the first occasion on which the forgeability of high-speed steel has been investigated. Robin[2] covered the field very widely in 1910, and the results of his tests on 2 W-Cr steel arc shown in Fig. 1. Whereas Robin determined the energy required at various temperatures to reduce normal samples of steel 20% in height—using in most of his experiments samples 15 mm. (0.59 in.) in diameter, the authors held constant the energy of the blow applied to their samples, measuring the percentage reduction in height subsequent to deformation at the various temperatures used.

The curve in Fig. 1, which passes through the closed circles, refers to a steel containing 0.7% C, 4.5% Cr, and 11.0% W; that passing through the open circles refers to a steel of high Cr and W content, its analysis being 0.7% C, 6.5% Cr, and 21.0% W. It is somewhat difficult to understand why the steel of lower Cr and W content should have been so distinctly superior to that of the higher Cr and W content in its resistance to deformation at temperatures below 600° C. One can but surmise that the latter had been annealed prior to test, while the former was tested in the air-cooled state. At temperatures above about 800° C. the resistance of the 2 steels to deformation was practically the same, the effects of air-cooling on the forgeability of these steels having been practically removed at temperatures above 600° C. and distinctly eliminated at temperatures of 800° C. and above. Robin's tests support the view that variations in Cr and W content (from 4.5 to 6.5% and from 11 to 21%, respectively) are practically without effect upon the forgeability of high-speed steel at temperatures above about 600° C.

It may be of interest to quote Robin's remarks on his experiments on these steels:

"High-speed tool steels offer the highest resistance to crushing. The steels investigated were sorbitic steels; their ball hardness was relatively inconsiderable, their resistance to abrasion was remarkably small, and their resistance to crushing shocks was higher than that of any other steel.

"This resistance to crushing perseveres in an interesting manner in terms of increasing temperatures, and the curves obtained strongly recall the hardness curves already studied in terms of the temperatures. At low temperatures the curves rise rapidly and at —185° reach a very high value. Generally speaking, it is in the vicinity of 500° that the fall in the resistance of these steels occurs. Their characteristic curve is almost rectilinear at high temperatures, and at 1100° their resistance is normally double that of dead mild steel."

It is somewhat remarkable that Robin failed to observe the fact that the steel lower in W and Cr was less forgeable than that higher in W and Cr at temperatures below about 600° C. While the authors believe that the difference is to be accounted for by the fact that the harder steel was in the air-cooled condition prior to forging, it must be remembered that the final word can be given only by one who has conducted experiments for the express purpose of explaining this discrepancy.

The results of the authors' tests on the steel from Henry Disston and Sons, Inc., are shown graphically in Figs. 2 and 3. In Fig. 2 the results of single tests are shown by individual circles, some of which are closed

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**Ontario Research Foundation, Toronto, Canada.

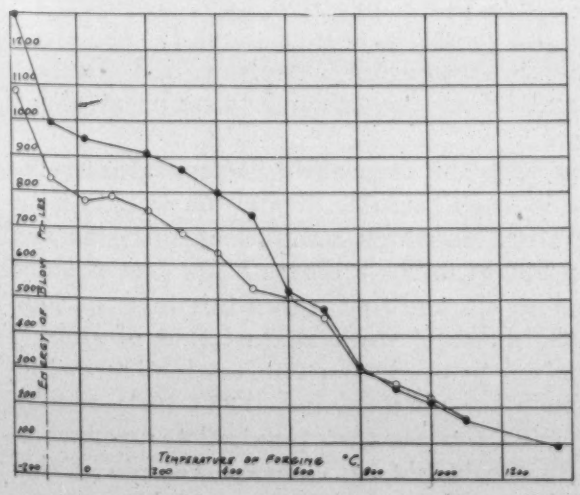


Fig. 1

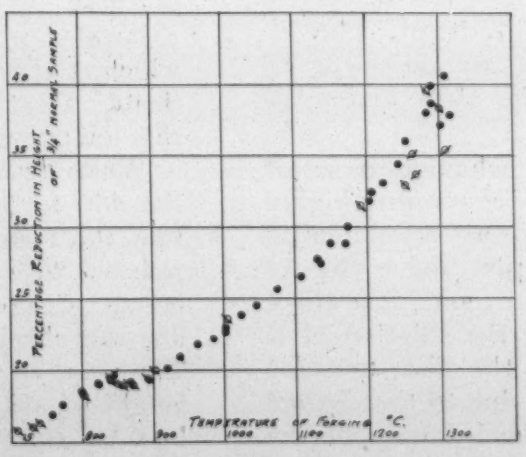


Fig. 2

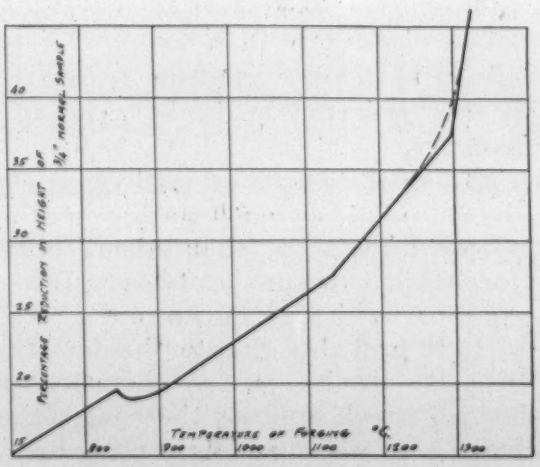


Fig. 3

and some open. The closed circles refer to the results of tests prior to which the samples had been heated to and held at the forging temperature for periods of 10 minutes (for samples heated above 1000° C.) and 12 minutes (for samples heated below 1000° C.), respectively. The open circles having lines drawn NW to SE refer to the results of tests prior to which the samples had been heated for periods longer than 12 minutes—generally 15 minutes. The open circles having lines drawn NE to SW refer to results of tests prior to which the samples had been heated for periods of less than 12 minutes—generally 5 minutes. The results of these last tests might well be disregarded, since the samples had not reached the forging temperature when they were placed upon the anvil of the forging machine.

It may be noted in passing that a sample forged at 1347° C. was flattened into a disk less than 1/8 inch thick under the standard blow of 532 foot pounds which was used in all these tests. This disk was badly fissured, and during forging liquid was violently extruded from the sample. A sample heated at 1386° C. collapsed when the attempt was made to remove it from the heating furnace to the anvil.

In Fig. 3 what is believed to be the forgeability-temperature relationship for this steel is shown. The points of special interest are:

(1) Clear evidence of atomic rearrangement at 840°-850° C.
(2) Evidence of structural alteration at 1135° C.
(3) Evidence of structural alteration at 1300° C.

Only in electrolytic iron and low C steel has the rearrangement of atoms which occurs at A3 produced so marked an effect on forgeability as that shown at 840°-850° C. in the forgeability-temperature relationship for this steel (Fig. 3).

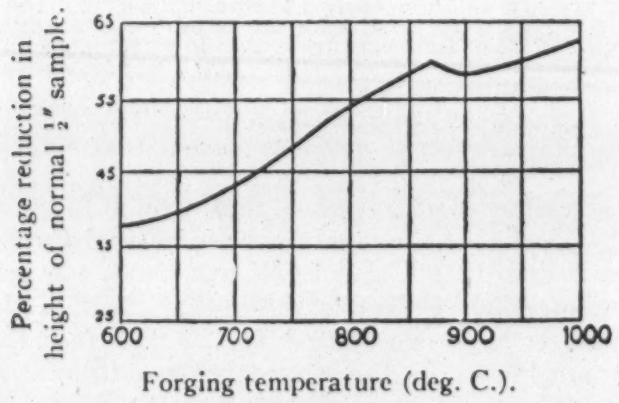


Fig. 4

Fig. 4, reproduced from the senior author's 1924 Carnegie Scholarship Memoir, shows very clearly the marked effect which the lower allotropic transformation has upon the forgeability of mild steel. It will be noted that the resistance to plastic deformation of this 0.08% C steel is distinctly greater at temperatures just above the A3 point (870° C.) than at the A3 point, itself. The increase in density resulting from the lattice change at A3 is thus reflected in the behavior of the alloy under the hammer.

C has the effect of modifying the behavior of Fe at the A3 point; so much so that in alloys containing higher proportions of C than about 0.08% no reduction in forgeability occurs at temperatures just above the A3 point, as is clearly shown in Fig. 5. The modifying effect of C is probably due to the fact that the solution of C in γ-Fe results in an expansion of the face-centered lattice, which opposes the contraction due to the change from α to γ-Fe[3] and is reflected in the behavior of the steel under compression. A marked decrease in forgeability at temperatures just above the A1 point of the high-speed steel would most certainly not be looked for in a straight C steel containing 0.70% C (Fig. 5). One is driven to the conclusion, therefore, that the W, Cr and V present in high-speed steel account for the considerable decrease in forgeability which occurs at temperatures just in excess of 840°-850° C; the rearrangement of the atoms of Fe, W, Cr, V and C at the A1 point

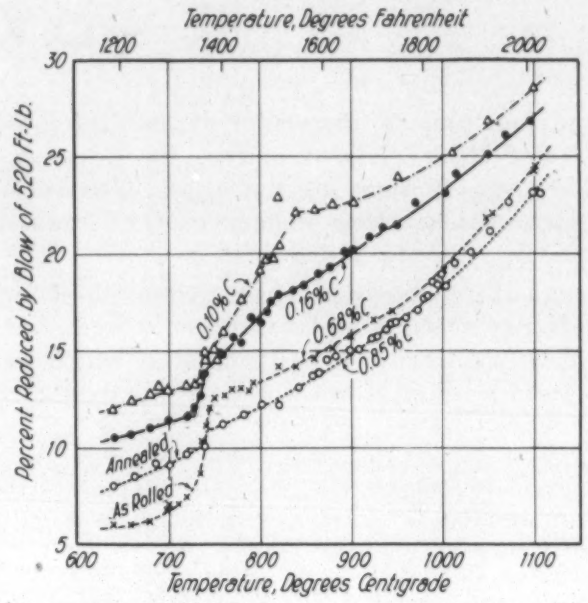


Fig. 5. Forgeability-Temperature Relationships of Four Carbon Steels Tested Under Similar Conditions.

results in a denser material which is more resistant to plastic flow than that existing at temperatures below 840° C.

The change in direction of the forgeability-temperature curve at 1135° C. is without doubt due to the solid solution of the complex carbides in γ-Fe. These carbides lose their identity and become merged in the austenite when the temperature exceeds 1135° C. and, as a result, the steel becomes more plastic.

The authors are of opinion that a linear relationship exists between percentage reduction in height and temperature over the range 1135°-1300° C. The dotted line has been drawn to indicate a *possible*, though unlikely, form for the forgeability-temperature curve. The sharp change in direction which occurs at 1300° C. in the curve which the authors suggest as correct is due to the appearance of the liquid phase. This temperature, 1300° C., is the solidus for this steel.

It may be well to note that a slight inversion seems to occur at about 775° C. (see Fig. 2). This the authors have ignored in their draft of the forgeability-temperature relationship in Fig. 3, in view of the fact that the magnitude of the inversion is within the limits of error of these experiments. The inversion may, however, be associated with the magnetic change point for the steel, which Carpenter,[4] Yatzewitch,[5] Andrew and Green,[6] Scott,[7] Hoyt[8] and others have found to occur at about this temperature.

While dealing with the forgeability-temperature relationship for the 3/4-inch samples, it may be well to note that the temperature at which samples of this size are reduced 20% in height under a blow of 532 foot pounds is 920° C. (see Fig. 3), and that, given this information, one can check the authors' work against that of Robin. The energy required to produce a 20% reduction in the height of a 3/4-inch sample (volume, 0.331 in.^{3}) should be 0.331/0.162 = 2.04 times that required to produce a 20% reduction in the height of a normal sample of the size used by Robin (volume, 0.162 in.^{3}) in his experi-

ments, the results of which are shown graphically in Fig. 1. As already noted, the energy required to produce the 20% reduction in the authors' steel at 920° C. was 532 foot pounds; hence, that required to produce a similar reduction in the steel used by Robin at 920° C. should be 532/2.04 = 261 foot pounds. Reference to Fig. 1 will show that at 920° C. the energy required to reduce by 20% in height the 2 steels investigated by Robin was in the immediate neighborhood of 260 foot pounds, which is practically the same as the calculated value of 261 foot pounds.

It may be of interest to record that the forgeability-temperature relationship for a 0.91% C steel (¾-inch normal sample) is very nearly the same as that for this high-speed steel over the range 1135°-1300° C., but the energy of the blow required to produce equivalent deformations in the high-speed steel is about 2.3 times that required by the straight C steel. This result does not agree very closely with that of Robin, who apparently found that the resistance of high-speed steel was normally double that of *dead mild* steel at 1100° C. (see quotation above).

The effect of varying the energy of the blow by altering the height of the drop of the 113-pound hammer used in these experiments is shown by the following results which refer to tests carried out at a temperaure of 1045° C.

Height of Drop of Hammer (in.)	Energy of Blow (ft.-lbs.)	Reduction in Height of ¾-Inch Normal Sample (%)
8½	80	4.0
20½	193	9.9
32½	306	15.0
44½	419	19.8
56½	532	24.5

By using these results, yet another attempt may be made to check the authors' work by comparison with Robin's values. It will be noted that the energy required to reduce the height of a ¾-inch normal sample (volume, 0.331 in.^{3}) by 20% at 1045° C. is in the immediate neighborhood of 419 ft.-lbs. That required to deform a 15-mm. normal sample (volume, 0.162 in.^{3}) by a proportional amount should be approximately 419/2.04 = 205 ft.-lbs. Reference to Fig. 1 will show that the energy required to compress the steels used in Robin's experiments by 20% at 1045° C. was between 190 and 200 ft.-lbs., which is not far removed from the value estimated from the results of the authors' experiments. It may be noted in passing that the speed of impact in Robin's experiments was 20.6 ft./sec. in all cases, whereas that in the author's experiments varied with the energy of the blow, as may be gathered from the above table. Clearly, the speeds of impact in the 2 sets of experiments did not differ sufficiently to produce discrepancies between the results, given blows sufficient to produce a 20% reduction in the height of the sample.

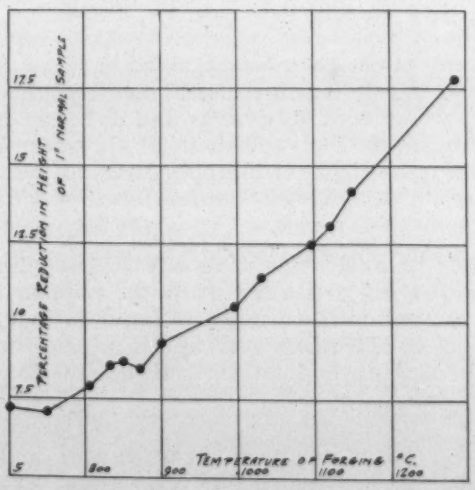
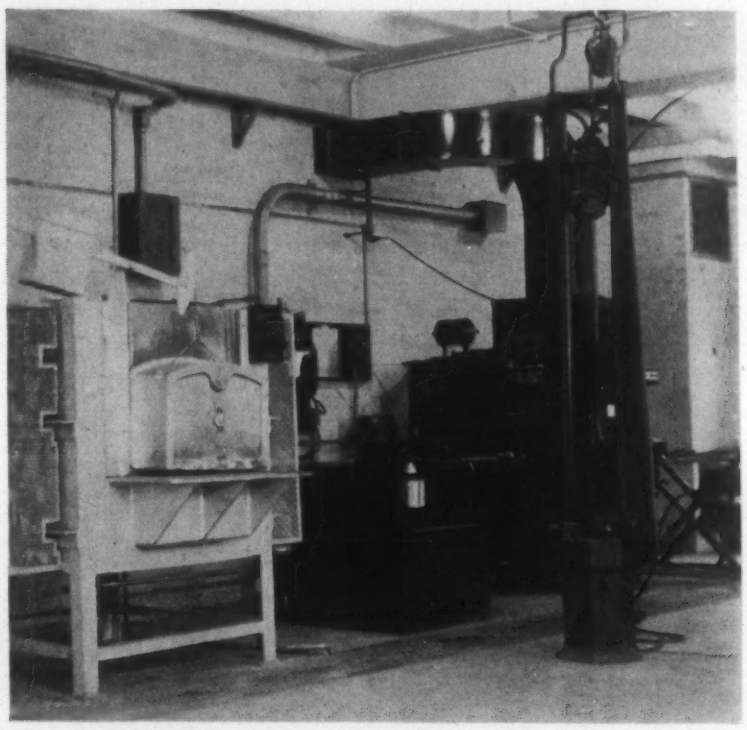


Fig. 6

Experiments were made on a number of samples cut from the 1-inch bar, and the results of these are shown in Fig. 6. In these experiments the energy of the blow was 532 ft.-lbs. It will be noted that the inversion at 840°-850° C. is shown quite distinctly, and that there is evidence of change in direction at about 1135° C. These results may be compared directly with those shown in Fig. 5, the energy of the blow used being practically the same in all cases. The comparison will be of interest as showing the relative resistance to deformation of high-speed and straight-carbon steels.



Equipment Used in Forging Tests

In the senior author's article[1] on "The Forgeability of Steel as Influenced by Composition and Manufacture," it was shown that: "If E be the energy in foot-pounds required to produce a certain definite percentage reduction in height D of a normal sample ½ inch in diameter by ½ inch high, then E and D are related by the following equation:

$$\log E = \log b + (1.56 - 0.47 \log b) \log D \quad (1)$$

where b is a parameter which can be found by making one drop test on the steel being investigated at the temperature in question." In order that this equation may be applied to normal samples of all sizes, it is necessary to bear in mind Tresca's theorem, which may be expressed mathematically thus: $E_1:E = V_1:V$. To make equation (1) applicable to 1-inch normal samples, it needs to be altered as follows:

$$\log E = \log 8 + \log b + (1.56 - 0.47 \log b) \log D. \quad (2)$$

Using equation (2), it is possible to determine the amount of energy required to reduce a 1-inch sample by a specified amount, knowing the percentage deformation D produced by a blow of given energy content E. For example, a 1-inch normal sample used in the tests referred to in Fig. 6 was reduced 7.9% in height at a temperature of 806° C. In this case the parameter b, as determined from equation (2), is 55.91. By substituting this parameter in equation (2), the amount of energy

required to reduce the 1-inch sample 18.5% in height can be determined; this is 1238 ft.-lbs. By using Tresca's equation and the value 1238 ft-lbs. obtained above, it can be shown that the energy required to produce an 18.5% reduction in height in a 3/4-inch sample should be $1238 \times 27/64 = 522$ ft.-lbs. Reference to Fig. 3 will show that a 3/4-inch sample is deformed 18.5% at about 806° C. under a blow of 532 ft.-lbs. Actual experiment, then, shows the energy required to deform a 3/4-inch sample by 18.5% to be 532 ft.-lbs., while an estimate of the energy required to deform the same sample, obtained by using equation (2), gives 522 ft.-lbs., which is not far removed from the experimental result.

The satisfactory results which are obtained with equation (2) when D is relatively small are not obtained when D is relatively large. For example, at 1275° C. a 1-inch sample is reduced 17.5% in height under a blow of 532 ft.-lbs. In this case the logarithm of the parameter b is —0.2773. By using this value it can be shown that the energy required to reduce a 1-inch sample by 36.0% in height is 1805 ft.-lbs. Tresca's theorem would indicate that the energy required to reduce a 3/4-inch sample by 36.0% in height at 1275° C. would be $1805 \times 27/64 = 762$ ft.-lbs., which is a little more than 43% greater than the energy found to be required by actual experiment (see Fig. 3).

It appears, then, that the equation obtained by the senior author might be used to estimate the energy required to deform normal samples of high speed steel of various sizes by relatively small amounts, but that it fails to give correct results when relatively large deformations are being considered.

In conclusion, the authors desire to express their appreciation of the kindness of Mr. H. B. Allen in supplying the steel for investigation, and of the interest shown in this work by Dr. H. B. Speakman, director of the Ontario Research Foundation.

References

[1]An Investigation into the Effect of Constitution on the Malleability of Steel at High Temperatures, Part I, *Iron & Steel Institute, Carnegie Scholarship Memoirs,* Vol. 13, 1924, pages 47-81; Part II, Vol. 15, 1926, pages 195-215. Forgeability of Steel as Influenced by Composition and Manufacture. *Metal Progress,* Vol. 22, Sept., 1932, pages 19-23.

[2]The Resistance of Steels to Crushing. *Iron & Steel Institute, Carnegie Scholarship Memoirs,* Vol. 2, 1910, pages 70-270.

[3]Andrew, Rippon, Miller & Wragg. *Journal Iron & Steel Institute,* Vol. 101, 1920, pages 527-608 (see, in particular, pages 546-547).

[4]Carpenter. *Journal Iron & Steel Institute,* Vol. 67, 1905, pages 433-473.

[5]Yatzewitch. *Revue de Métallurgie,* Vol. 15, 1918, pages 65-112 (see, also, Sauveur. The Metallography and Heat Treatment of Iron and Steel, 3rd Ed. McGraw-Hill Co., 1926, pages 348-352).

[6]Andrew & Green. *Journal Iron & Steel Institute,* Vol. 99, 1919, pages 306-336.

[7]Scott. *Scientific Papers, Bureau of Standards,* No. 395, 1920, pages 521-536.

[8]Hoyt. Metallography, Part II. McGraw-Hill Co., 1921, pages 447-448.

READERS' COMMENTS

More Heat Resisting Alloys

Editor, METALS & ALLOYS:

We are taking the opportunity to express some points of view in relation to the articles on Heat Resisting Alloys by Mr. Stanbery in the September and October issues, which I feel justified in stating, will be supported by the majority of that group which may be termed the "Pioneer" Alloy Manufacturers.

As stated in substance in his articles, there has been perhaps more misinformation on these alloys presented and written than on almost any other topic. This subject has been a prolific one for those with a yen for words and the spotlight. However, it occurs to me that certain statements need qualifying, and while it represents a very intelligent and well presented corollary of information it does not evidence appreciation of the fact that this is a pioneer business, young in history and a hazardous undertaking for those attempting to guide and follow it through the initial periods.

It is inferred by this and other articles on alloys that the manufacturers have been either in the dark or were adverse to publishing data already assembled. It may seem strange to some that a large portion of the information, or I might state "misinformation" on alloy, has been presented or published by individuals who have had only the merest contact with alloy problems, which in the final analysis consist not of one phase, but a comprehensive experience involving the stresses, design, applications, metallurgy, successful production technique and the development of a new industry requiring not only the pioneer spirit and a confidence in the future, but also in one's ability to go through to the extent of guaranteeing results at the obvious risk of one's reputation and money.

The first question is promptly disproved by the fact that heat treating machines of automatic character, both as to operation and control, have displaced hand-operated crude construction and methods. New processes based and depending in their entirety upon alloy structure and dependability have altered the economic status of several industries. This is not the result of guess work entirely.

It is also well to keep in mind that the alloy manufacturer was constantly called upon to guarantee the performance necessary to effect the economies hoped for, often untried and unproved applications, in which there was no previous history.

Intimate contact with serious problems is a very chastening and humbling influence and we cannot help but recall the expression—"Fools rush in where angels fear to tread."

In a pamphlet on alloys issued several years ago the following appeared in the Foreword:

"It is now generally conceded that economically certain units for use at elevated temperatures may be obtained only through the scientific application of appropriate materials correctly designed.

"In designing equipment for service at elevated temperatures the engineer is concerned with many problems. Given an alloy which will withstand the conditions of temperature and corrosion involved, successful designing must take into consideration the fact that allowable safe working stress is a variable factor.

"It is established that there is no definite value of yield point but that this factor varies not only with temperature but with duration of stress at any given temperature. It will be noted that high temperature tensile strengths given in the following pages are quoted as 'quick pull' tests and these should not be confused with so-called 'creep stresses.'

"Creep stress values thus far obtained have not proved absolutely reliable, but it has been established that safe working limits may vary between 50 pounds and 800 pounds per square inch, depending upon the conditions. It therefore is the policy of our engineers to study each application to the end that the most appropriate designs may be developed and the most suitable alloy employed for each set of conditions encountered."

It is difficult to avoid resenting any statement or inference that tends to detract from the work the pioneer alloy manufacturers have accomplished and the impetus that accomplishment has given to the placing of alloys among the useful and practical arts and opened an entirely new vista of methods, practices and economics.

Sept. 22, 1933
Michigan City, Ind.

W. B. SULLIVAN
Vice-Pres. & General Mgr.
Michiana Products Corp.

Editor, METALS & ALLOYS:

The reader who carefully examines my articles in the September and October issues on Heat Resisting Cr-Ni-Fe Alloys for Furnace Construction and Mr. B. J. Sayles' letter to the editor on page 165 of the October issue, commenting thereon, will be puzzled by Mr. Sayles' arguments in refutation of statements not made in the articles, and especially by his use of quotation marks about phrases not appearing in them.

When the material from which the articles were finally worked up was first sent to the editor for his comment and that of those experienced in this field, it contained many speculative points intentionally inserted to provoke discussion. Since Mr. Sayles' comments and those of several others who kindly went over this raw material, were utilized in the revision, the articles as they appeared in print were in many respects decidedly altered, and I trust improved, over their early form. When Mr. Sayles received the galley proof of the articles as they were actually to appear, he evidently did not bother to read them, but wrote his comments from his memory of the earlier draft. Only thus can I account for his misquotations and misinterpretations.

Even at that, his memory must have been poor, for at no time have I advocated the use of short-time tensile values as a basis for design. Nor am I "inclined to dismiss the so-called 'minor elements'—with too scant attention" in practice, as their adjustment holds great potentialities. But the proven facts as to the influence of these elements are too scanty and the ideas of various producers too contradictory to allow an extended discussion of their effect that would be on a par with the facts presented in the articles.

No discussion of the relative merits of acid and basic melting appeared in the articles and on that point Mr. Sayles' comment again refers to a section put into the original draft to draw discussion. Incidentally, the comments were by no means in agreement!

When Mr. Sayles' discussion is purged from its comments on matter not included in the articles, it will be found that he is actually pretty much in agreement with my statements that creep values are the best basis so far available for design (and the articles cite all published creep values) that the fifth power approximation does not necessarily hold, but is only to be used as a fair guess when nothing better is available, etc., etc., and that his only real quarrel is with the classification of the alloys into groups and with the implication which he apparently derives from the classification, that specifications should be set up under which a number of manufacturers might bid. Such classification and specifications it is admitted have some serious drawbacks if orders are awarded on the basis of price alone. Such a system, however, is reasonably successful if the specifications are backed up by a knowledge of the capabilites of the approved sources of supply, a close coöperation with them, and a careful check-up of the manufacturing methods and subsequent behavior of the alloys in actual service.

Unfortunately, the ideal set-up evidently advocated by Mr. Sayles, i.e., offering each job to a foundryman for analysis and price is impractical for the general industrial furnace business. The alloys must be classified after a fashion, and a cost per pound determined so that a basis of estimate is available before the furnace is sold and designed. The approximate costs must be known or else the estimate is liable to be so far in error that the job represents a loss instead of a profit. It is rarely possible to sell a furnace and then present the price after the job is built and installed!

I am fully aware of the fact that the true creep values for these alloys are not definitely known for all analyses and temperatures. The values offered in Part I, Fig. 13 are based on experience and a careful consideration of the possible operational factors entering into commercial equipment used at high temperatures. The errors introduced by the broad classification limits are no greater than the "wide variations in the strength results depending on manufacturing variables" (quoting Mr. Sayles), hence, it seems useless to attempt a more specific classification in the articles under discussion.

I am also aware of the differences of opinion as to what constitutes a "safe load" or "design strength" for a given typical alloy, such differences amounting to several hundred percent. Some of the values, it is true, may represent the "factor of ignorance." Since the producers themselves disagree so strongly, the only recourse for the designer is to study the whole subject and attempt a set of standards which represent a consideration of the foundry problems as well as his own specific requirements. Practical application of such standards plus adjustment due to experience will allow at least a more coherent set-up than that indicated by the present state of mind of the various producers.

The time is not far distant when the consumer is going to demand from the producer, definite information in the form of standards as to analysis and performance.

I surely did not intend to give the impression that the manufacture of alloy castings is seldom attended by successful results. Mr. Sayles will be the first to agree, however, that the subject is sufficiently complex and sensitive to warrant the maximum degree of coöperation between the designer and the foundryman. That is the sense of Part II where it deals with castings. I have had a certain small part in the successful application of several hundred thousand pounds of castings in industrial furnace equipment and am not inclined to state that the applications were seldom successful. Indeed it is remarkable how great the percentage of successful applications was when the paucity of real information from the producers is considered.

Mr. Sullivan's letter of Sept. 22 in comment on my articles on "Heat-Resisting Alloys" raises some points which are pertinent to the subject but I fear that he has read into the articles certain inferences which he considers unfair to the alloy producers. No such inferences were intended nor do I believe that they are justified by the text.

For the benefit of Mr. Sullivan and the group of pioneer alloy manufacturers who have struggled valiantly with a highly complex and often discouraging new metallurgical art, I hope that the reader will infer from the articles the facts that the art is young, estimates of strength and serviceability of the various types of alloys are based largely on experience, and that the best assurance that an application will be successful will be given by a close cooperation between the designer and the producer. That, I think, will be the inference that any user will derive from a careful reading of the articles.

It may be in order to repeat an opinion which was expressed near the end of Part I in the September issue to the effect that the time is ripe for a joint research on these alloys and the establishment of tentative standards which will represent the views of both manufacturer and user. Such action would be far more effective in quieting the user's mind than a series of meetings which have had as a primary object discussions of prices and debates on the evils of price-cutting. The question of prices is important but authoritative information as the result of an intelligent research would seem to be equally important.

Oct. 12, 1933
Toledo, Ohio

L. J. STANBERY

Beg Your Pardon

In the August, 1933, issue of METALS & ALLOYS on pages 119-122 an error was made by interchanging illustrations. The cuts at the top and bottom of pages 120 and 121 were turned end for end; that means that what is shown as Fig. 5 should be Fig. 3, Fig. 10 should be Fig. 8, Fig. 13 should be Fig. 11, Fig. 17 should be Fig. 14 and Fig. 16 should be Fig. 15.

OBITUARY

John Clifton Henderson, inventor of cast "Nichrome," died in the Elizabeth General Hospital, Sept. 25, 1933. He was 56 years old. Mr. Henderson held 30 or more patents and for the last 20 years has been Consulting Engineer at the Driver-Harris Company, Harrison, N. J. His first patent on cast carburizing containers made of the alloy "Nichrome" was taken out about 20 years ago.

Charles Piez, who with Charles M. Schwab directed the Wartime work of the Emergency Fleet Corporation, and friend of President Franklin D. Roosevelt, died today (October 2), at the Garfield Hospital, Washington, D. C. Mr. Piez was Chairman of the Board of Link-Belt Company, Chicago. His last appearance in official circles was as a dinner guest of the President at the White House recently.

Mr. Piez was a past President of the American Society of Mechanical Engineers. He served twice as President of the Illinois Manufacturers' Association. The deceased was 67 years old. While pneumonia was the direct cause of his death, his health had been failing for the past 5 years, and since Feb. 1932, he had been wholly inactive in business. Last May Mr. Piez moved from Chicago to Washington, where he made his home at the Shoreham Hotel.

Running Quality of Molten Metals*

Its Application to Study of Iron-Carbon Alloys

by M. René Berger

Extended Abstract by A. I. Krynitsky

IN HIS study of the running quality of molten metals and alloys Prof. Portevin came to the following conclusions:

1. The running quality depends on many factors of which the caloric properties of metals (specific heat of molten metal and heat of solidification) are at least as important as is the viscosity.
2. For the same temperature of superheat the running quality of alloys is in an inverse relation to the interval of solidification.
3. The running quality appears to have a relation to crystallographic structure of elements which are deposited during solidification.

In his investigation the author employed the method proposed by Saito and Hayashi and modified by Remy and Cury.

Green sand molds (moisture 4.5%-5%) were used. Molding machine was used to prepare the molds.

In order to minimize the friction between the molten metal and the mold a round cross section of the spiral was adopted instead of a triangular one used by Cury. The diameter of this cross section was 8 mm. (area 50 mm.²). The height of the down gate was 200 mm. (230 cc. capacity). The arrangement of the spiral, the drag and cope parts of the mold are shown in Fig. 1.

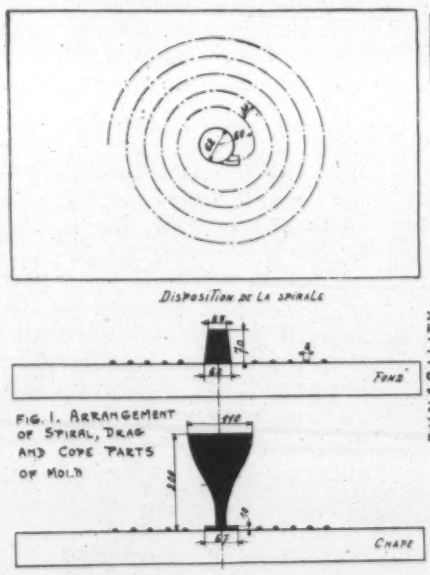


FIG. 1. ARRANGEMENT OF SPIRAL, DRAG AND COPE PARTS OF MOLD

In order to secure a constant velocity with which the molten metal filled the mold the following scheme was adopted:

Two basins A and C (Fig. 2) were connected with a down gate B by channels D and E. The metal entered basin A and flowed into downgate B from the constant height of 150 mm. When the metal entered basin C the pouring was stopped, the pressure of the molten metal then corresponding to the height of 175 mm.

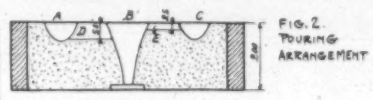


FIG. 2. POURING ARRANGEMENT

Cury's filter core was first omitted; later on, however, it was introduced at the bottom of the down gate in order to secure a greater precision of the test.

If the cross sectional area of spiral is smaller than that of the filter then the area of the spiral controls the velocity of the flow; on the other hand when the cross sectional area of the spiral is larger than that of the filter, then the latter is a controlling factor.

Results showing the effect of the diameter of a core filter on the length of spiral are given in Table I.

Table 1.—Lengths of Spirals Corresponding to Different Diameters of Core Filter

Diameter of Filter in mm.	5	7	8	10	15
Length of Spiral	39	50	53	64	65
	39	42	47	49	49
	60	82	....	95	97

From his experimental data and calculations of the maximum possible errors of observations the author came to the conclusion that the diameter of his filter should be 10 mm. and that a vent of 8 to 10 mm. must be employed.

Although the presence of a vent caused a decrease (about 4.5%) in length of the spiral the author preferred to sacrifice the sensibility of observations in order to obtain greater precision.

Original Article "Mise au point d'une Eprouvette de Coulabilité et son Application a l'Etude du Système Fer- Carbone." *Association Technique de Fonderie de Belgique*, No. 17, Aug. 1932. Institut de Metallurgie de l'Université de Liege.

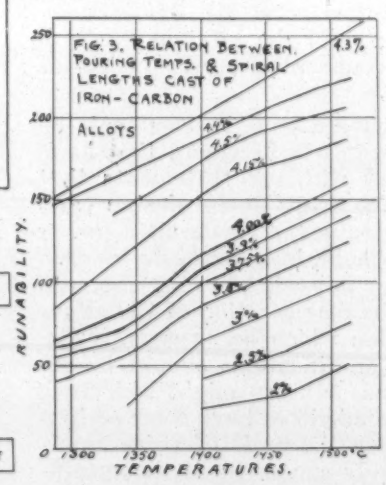
It was also found that in order to insure still greater precision the time of casting the spiral should be 4 seconds. The length of spiral was increasing with an increase in pouring time up to 4 seconds. With a further increase of time the length of spiral remained almost constant.

The method described above was used in the study of iron-carbon alloys. Alloys were prepared in crucibles in a coke fired furnace. The maximum heating temperatures varied between 1500° and 1550° C.

The initial composition of the cast iron was as follows:

Si	Mn	P	S	C
0.21%	0.02%	0.08%	0.026%	4.15%

During melting a well pronounced decarburization took place. At the same time there was considerable loss of silicon, the content of which during melting was reduced to an amount smaller than 0.1%.



Alloys containing a large amount of carbon were obtained by placing an excess of a fine pulverized anthracite on the bottom of the crucible.

In order to insure recarburization it was necessary to heat the charge to at least 1530° C.

Each charge weighed 40 kg. which was sufficient to cast 3 molds. An optical pyrometer was used. Temperatures which are given in the paper were direct temperature readings without any emissivity correction.

At temperatures above 1250° C. a bright film of oxides appeared on the surface of molten metal and there was a great evolution of brown fumes of iron oxide, which made temperature readings more difficult and less correct. The following conclusions were drawn:

1. For the same pouring temperature the running quality of iron-carbon alloys increases with an increase in carbon content up to eutectic concentration (4.3% C.) and then decreases with a further addition of carbon.
2. In the hypoeutectic alloys there was observed a sudden increase in runability at 4% C.
3. The curves showing a change of running quality with pouring temperatures for different carbon contents are presented in Fig. 3.

Table 2 shows the runability values for different carbon contents at pouring temperatures 50, 100, 150, 200, 250, and 300° C. above the liquidus.

Table 2. Lengths of spirals cast of alloys containing different amounts of carbon at temperatures above the liquidus as indicated.

%C	Temperature of Liquidus	Superheat 50°	100°	150°	200°	250°	300°
		Centigrade					
2.00	1390	37	40	55	.....	.....	.....
2.50	1350	41	55	75	.....	.....	.....
3.00	1300	35	64	80	100	.....	.....
3.50	1250	45	60	85	102	125	.....
3.90	1225	55	68	92	117	135	153
4.00	1200	....	70	87	116	137	155
4.15	1175	....	80	108	138	164	179
4.30	1145	....	143	170	176	200	212
4.40	1160	....	140	163	172	192	210
4.50	1162	....	.....	140	158	180	195

Abstractor's Remark

There is no indication in the paper that a thermocouple was used. Liquidus temperatures evidently were taken from iron-carbon diagram. It is also doubtful whether correct temperature readings could be obtained by means of the optical pyrometer, particularly at low temperatures.

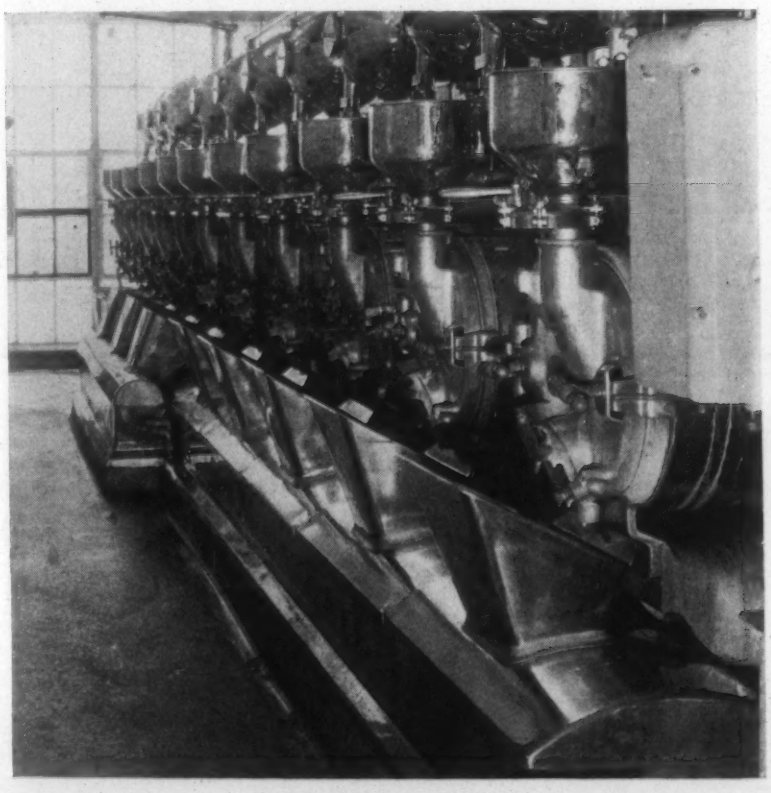
Chromium-Nickel as a Corrosion Resistant Alloy

by Robert J. McKay*

PART I. INTRODUCTION

Principal Constituents

CHROMIUM and nickel are the principal elements alloyed with iron to produce the "stainless" or rust resisting steels. Chromium itself is highly resistant to corrosive oxidation and imparts this property to iron when alloyed with it. The same effect is observed in combinations with other metals as well. Nickel has several effects in the stainless alloys, probably the most useful being to increase toughness and ductility. Nickel in the commercially pure state is widely resistant to acid, alkali, and salt corrosion, but is not free from surface oxidation and tarnishing. The addition of about 14% chromium to nickel produces a stainless surface, strengths rising into the alloy steel range and working properties more akin to pure nickel than to the more recalcitrant stainless alloys.



Ice Cream Hoppers

The cost of raw materials is only one of the items making up the cost of high grade alloys and it may be offset by efficiency in metallurgical and production methods. The stainless steels, however, contain over 70% of iron as compared with 6% in this alloy and will probably always be made somewhat more economically. Thus the field of usefulness of the new composition is in such boundaries of the stainless field as require resistance to specific corrosives, amenability to drastic fabrication methods, or where proper heat-treatment is inconvenient. In equivalent shapes the cost seems to be slightly over that of pure nickel.

History

No particular originality of thought is claimed for the introduction of the alloy mentioned as a new commercial product since its properties are quite in line with expectations from the components. Alloys not very different from it have been used for many years—their stainless or corrosion resistant property being only one of several contributing to their success.

*In charge of Technical Service on Mill Products, International Nickel Company.

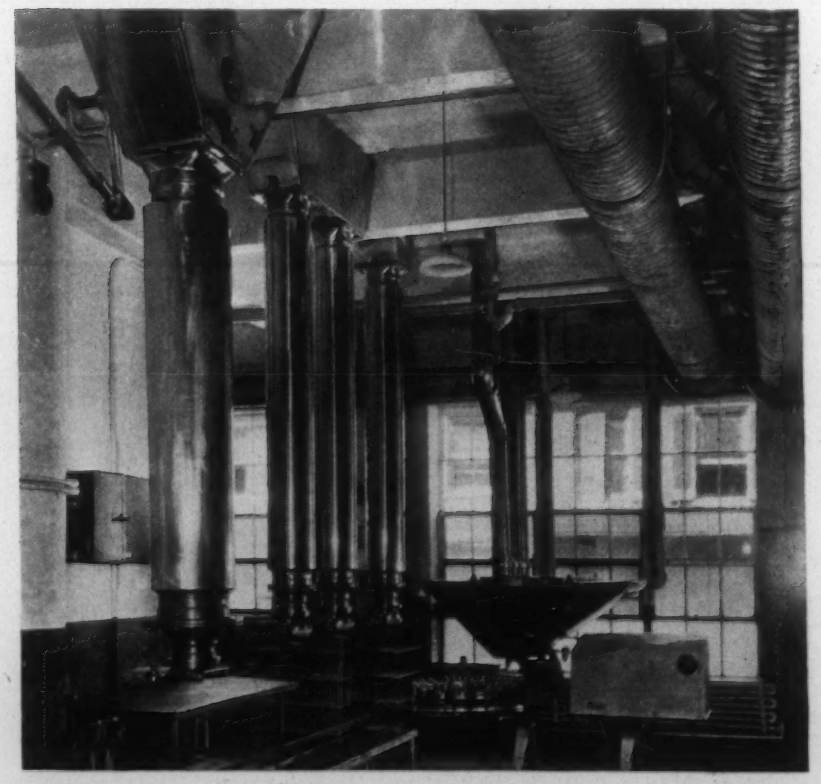
A series of tests on the corrosion resistance of such alloys was begun in the laboratories of the International Nickel Company some years ago and quite favorable results were obtained. The industrial significance of the results was doubtful at first but as they progressed there has been a parallel growth of public interest in alloys with a bright metallic surface, high strength, favorable working properties and freedom from deterioration in service. These coincidences induced a complete study of these and other properties in the industrially useful forms of the alloy.

The reader is here reminded of certain desirable attributes of a construction "metal." It should be strong. It should be malleable and ductile enough to form into complicated hot or cold shapes; it should make good castings; it should be capable of joining to itself and other materials easily, preferably by a number of methods; it should be amenable to machining and cutting operations; it should allow of strengthening and softening; its properties should be unchanged with time or temperature in service. (Sometimes low expansion with heat is desirable and in cases there are specific requirements for heat conductivity, electrical conductivity, and magnetic permeability.) The summation of these properties determines the general utility. A reasonably high quality in each is helpful except in special cases.

The laboratory development procedure took the form of making up small melts of a range of compositions, varying the nickel, chromium, and iron contents; also heats containing special addition agents, and examining these for the several necessary qualities as outlined above. As conclusive tests as possible were made on all properties and careful judgment was used in calculating the value of composition changes which improved one quality and changed another unfavorably.

Composition

In the range of the finally accepted composition, which was 12-14% Cr, 5-6% Fe, balance commercial Ni, variation in each major component had its typical effect. Raising the chromium



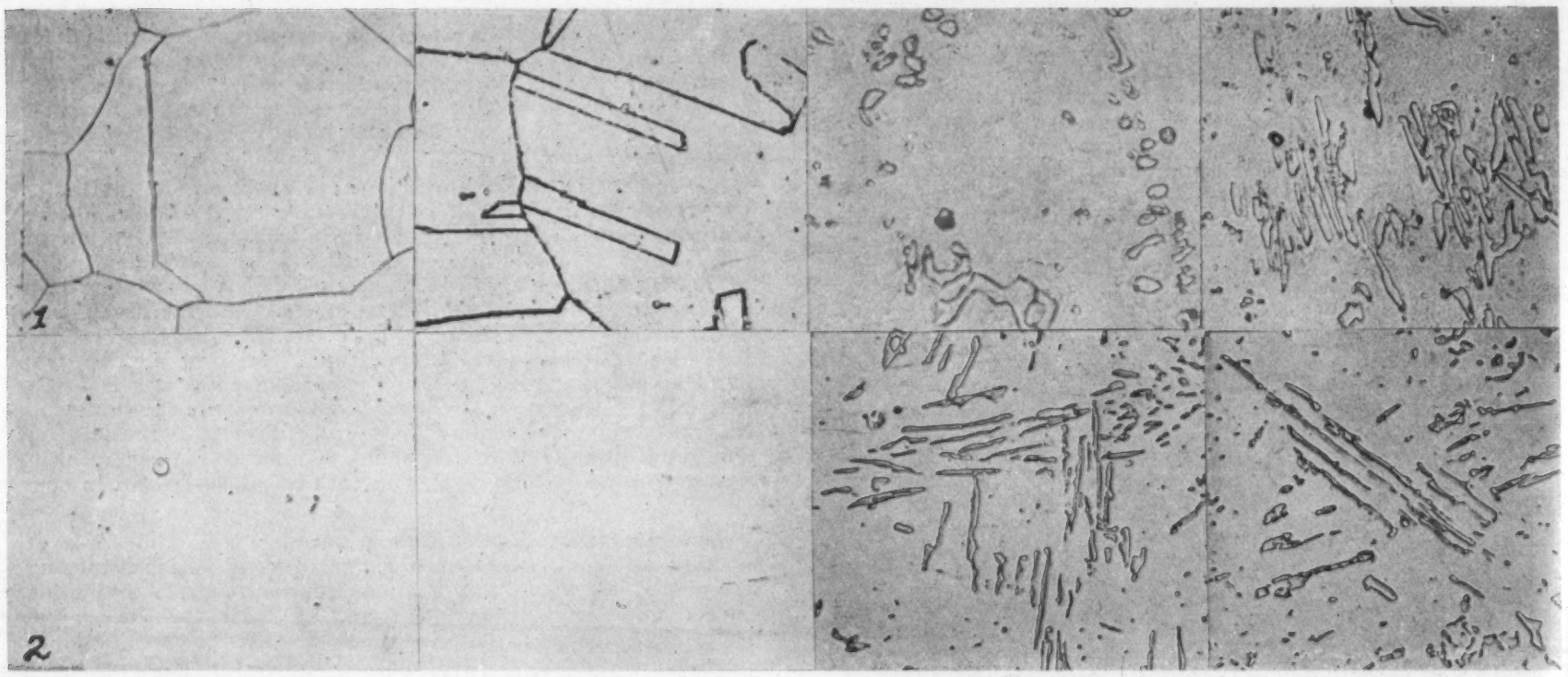
Ice Cream Conveyor Tubes

improved the stainlessness and strength somewhat at the expense of the working qualities and without change in the acid resistance and general corrosion. Change in the iron content had little effect on any of the properties up to about 20 to 25% where there began a slight tendency to rusting under drastic reagents and some change in the welding characteristics. High nickel contents improved the general workability; reduced the welding facility; improved the acid and general corrosion resistance, and reduced facility of casting.

The carbon content of high nickel alloys has a different effect from carbon in steels.[1,2] There is no series of superimposed solid phases dependent on the carbon content. Increase in carbon has a merely preceptible hardening and strengthening effect and causes no change in the corrosion resistance. There is no precipitation hardening or embrittlement from carbide precipitation.

Fig. 1. Magnification 500 X; Etched as anode in 30% H_2SO_4: Water quenched from 2200° F. and drawn 16 hours at 1200° F.

.02% C. Sheet | .13% C. Rod | .44% C. Casting | 1.04% C. Casting



.13 % C. Rod quenched | .13% C. Rod drawn | 1.04% C. Casting quenched | 1.04 % Casting drawn

Fig. 2. Magnification 500X; etched in Murakami's reagent.

Carbides were not precipitated by drawing at 1200° F. in metal containing less than about .2% C, but are precipitated readily either when quenched from 2200° F. or drawn at 1200° F. in metal of .5% C or over (See Figs. 1 and 2). Carbide is visible in .44% and 1.04% castings as large outlined areas, none visible in sheet or rods. The constancy of effect under varying heat treatment is of practical value in making the alloy more fool-proof in service.

Introductory Uses

The practical introduction of the alloy into specific uses illustrates the ensuing technologic properties and engineering data. The preliminary laboratory studies having been made principally with food cooking and handling in view, the first uses of the metal were in the manufacture of apparatus for the treating and handling of milk. These uses have now spread into broader fields by natural selection.

The usual rigid inspection in milk handling emphasizes the tarnishing of nickel which in some cases is rather striking. The new composition, which is being called Inconel, being free from this effect and being readily formed and welded into the desired "sanitary" shapes has been well adapted to the manufacture of the appropriate machines. The high nickel content of the alloy prevents pitting by the cooling brines which become very corrosive by hydrolysis during use. The high strength facilitates simple design of special shapes and the low expansion coefficient allows rapid temperature changes in pasteurizing and refrigerating without disturbing alignment of parts. (Fig. 3.)

A direct result of the service success of milk handling equipment has been the use in apparatus for handling and packing the more corrosive and delicate foods, such as high acid fruits and meats. The high strength and facility of welding has caused a natural demand for the alloy for steam jacketed kettles for factories and large kitchens. These kettles require mechanical strength to withstand steam pressure as well as accuracy and beauty of finish. (Fig. 5.)

Welded tubes retain their properties after severe bending in making heating unit sheaths for electric stoves and endure repeated heating and cooling with apparently less deterioration than units of any comparable alloy. High strength wire drawn with relative ease and withstanding atmospheric corrosion has produced insect screen which combines visibility, permanency, and freedom from staining better than any former screen. These illustrations are uses which have proven economical and possibly indicate properties better than would a longer hypothetical list.

Inconel has been bonded to steel in much the same way as pure nickel. The properties of the bond, the ease of fabrication, and the conditions of economical use are closely parallel with nickel-clad steel.[3,4] Of course the corrosion resistance is that of Inconel rather than nickel, strengths are slightly higher and welding facility is greater.

PART II. CORROSION RESISTANCE

Food Handling

Assuming that the reader is familiar with the high acid, alkali and salt resistance of nickel, the freedom from staining or tarnishing of the 14% chromium-nickel alloy becomes its outstanding corrosion resisting characteristic. This feature is critical in all food handling as it is favorable for detection of contamination. It also makes cleaning a positive and easy procedure.

Spot tests have been made by placing food products on the clean metal surface and allowing to stand for long periods. Containers have been made up and cooking operations carried out in the laboratory, home, and factory. These tests have furnished definite data on some 30 different common conditions of food handling selected as conditions which may affect metals or enamels. None of these tests have shown visible tinting or other significant attack.

Recent propaganda on the dangers of metals in handling foods have, in the writer's opinion, been exaggerated. However, the possible hygienic significance of contact of foods with the alloy has been studied and assurance obtained that no danger is to be anticipated.[5,6]

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[1]Nickel. *Bureau of Standards Circular* 100, 1921.

[2]P. D. Merica & R. G. Waltenberg. Malleability and Metallography of Metals. *Bureau of Standards Technologic Paper* 281, Vol. 19, 1924, page 155.

[3]William G. Humpton, F. P. Huston & Robert J. McKay. Nickel-Clad Steel Plate Work. *Mining & Metallurgy,* Vol. 12, 1931, page 90.

[4]Methods for the Fabrication of Nickel-Clad Steel Plate. Bulletin T-4, International Nickel Company.

[5]Drinker, Fairhall, Ray & Drinker. The Hygienic Significance of Nickel. *Journal of Industrial Hygiene,* Vol. 6, 1924, page 307.

[6]Titus, Elkins, Finn, Fairhall & Drinker. Contamination of Food Cooked or Stored in Contact with Nickel-Chromium-Iron Alloys. *Journal of Industrial Hygiene,* Vol. 12, 1930, page 306.

Atmospheric Corrosion

The freedom from staining observed in foods is also extended to atmospheric exposure. Comparative exposure tests of forging and sheet samples, varying in chromium, have been made in a variety of atmospheres over a period of 4 years. While it cannot be claimed that the selected alloy is chemically free from atmospheric corrosion it is clear from these tests that it is essentially so, being less affected than common alloys which are considered immune. The tendency of nickel to form an adherent tarnish in ordinary city air is effectively counteracted and the exposed surface retains its color and to a certain extent its brilliance even after long exposure.

For quantitative figures on atmospheric exposure, it is convenient to turn to exposures of woven wire insect screen made in representative localities. Tests were made in sea air at Brigantine, N. J., in industrial air at Bayonne, N. J., and in country air near Phillipsburg, Pa. The following tabulation shows results:

TABLE I.

Atmosphere	Sea	Industrial	Country
Original strength of .009" wire	6.5 lb.	6.5 lb.	6.5 lb.
Loss after 5 mos.		5.6%	3.2%
Loss after 14 mos.	8.5%	10.4%	7.2%

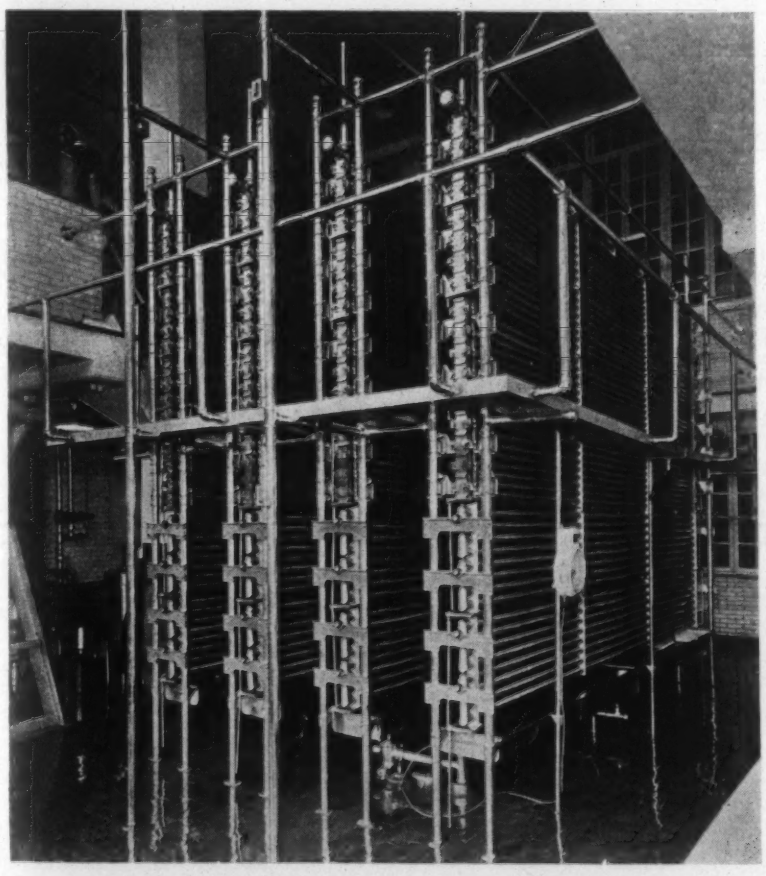


Fig. 3. Inconel Tubes, Sheet and Castings Regenerators and Surface Coolers Fairfield-Western Maryland Dairy, Baltimore.

The limit of useful life cannot be predicted by such measurements, but from them and other comparative data it is estimated to be very long in terms of experience with other screen materials.

Comparative exposures were made with a representative stainless steel in an atmosphere of heavy smoke and in country air with the following results:

TABLE II.

Atmosphere	Heavy Smoke	Country Air
Loss Stainless (18-8)	5.1% per mo.	1.2% per mo.
Loss of Inconel	2.1% per mo.	.51% per mo.

In all exposures of screen the easy removal of dirt deposits discloses a clean metallic surface. In country air there is no appreciable dulling of luster after 2 years exposure.

Comparative exposure tests were made of Inconel screens with Monel metal, bronze, and stainless steel with the following results. The indicator used was the discoloring of white lithopone painted wooden frames in which the screen were installed. This indicator was selected because the discoloration of frames is probably the major visual effect of corroding screens.

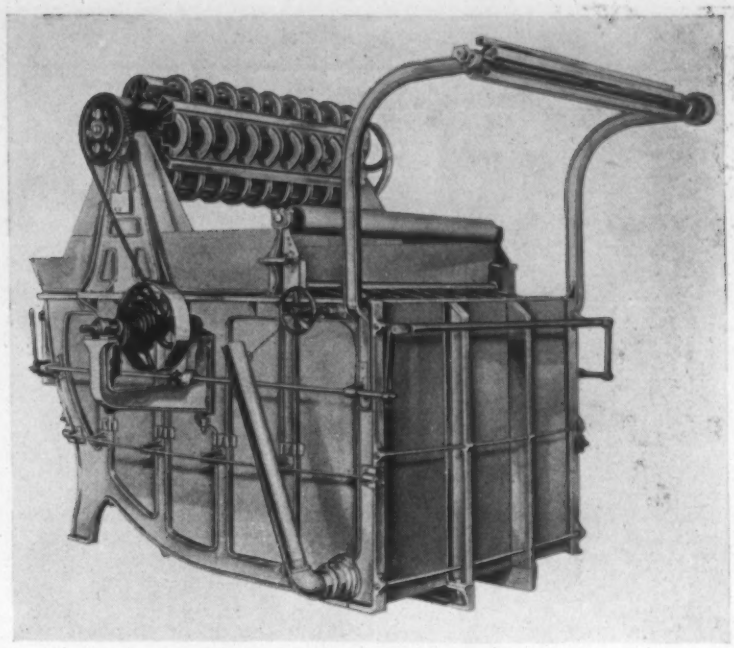


Fig. 4. Typical Dyeing Kettle

Table III. Degree of staining of paint by exposed screens

0 = none: 1 = trace: 2 = slight: 3 = moderate: 4 = considerable: 5 = heavy.

Air	Time of Exposure	Inconel	18-8	Monel	Bronze
Clean country	22 wks.	1	1	2	4
Marine	17 "	0	3	3	4
Industrial	19 "	1	3	5	5
High sulphur (Coal Smoke)	6 "	0	2	3	5

Brine Corrosion

Inconel cannot be said to be "absolutely resistant" to brines, but practical interpretation of tests show it to be of lifetime permanency in contact with ordinary brines. An outstanding quality is the freedom of joints from destructive local attack. In addition to riveted, soldered or brazed seams, the joints made by welding are not only free from internal deterioration but are usually less subject to attack than the parent metal. (Fig. 6.)

Welded equipment of Inconel has been in service in brines and under other conditions for some time now without the faintest signs of attack in the vicinity of welds. An accelerated test has been made by subjecting welded specimens to a solution of copper sulfate and sulfuric acid as used widely for testing the embrittlement susceptibility of metals. After 100 hours the Inconel specimen had lost none of its ductility, over a period of time when metal susceptible to embrittlement had suffered serious intercrystalline attack.

Table IV below shows the results obtained with several alloys tested:

Table IV. 100 day test in 16% Ca Cl Refrigerating Brine pH=5

Alloy	Penetration rate in critical zones inches	Over all corrosion inches
0 Cr; 99 Ni; .2 Fe	.004	.0007
8 Cr; 80 Ni; 2 Fe	.007	.00043
13 Cr; 80 Ni; 6 Fe	.006	.00046
18 Cr; 8 Ni; 74 Fe	.054	.00042
20 Cr; 79 Ni; .2 Fe	.016	.00049

It will be seen that with the exception of pure nickel the Inconel (13 Cr) composition has the lowest penetration rate of the commercial alloys tested. One of the comparison metals here, nickel, has had practical use in these brines for years without difficulty developing. While no doubt a composition might be found with better resistance to this specific form of corrosion, these figures are a sufficient guarantee that the resistance to brines is adequate.

Fig. 5. Inconel Jacketed Kettles

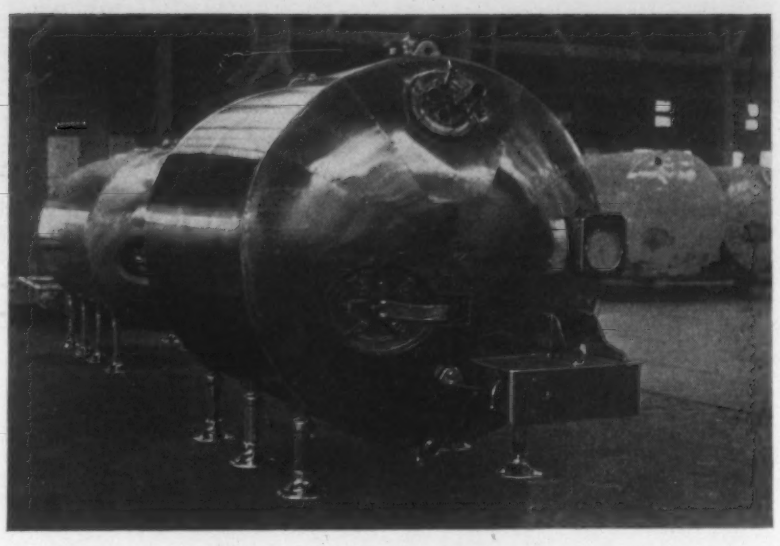


Fig. 6. Brine Jacketed Pasteurizer

The resistance of welds to this corrosion is of importance. As a matter of actual measurement it was determined that in tests where the average penetration in the sheets was .006″ in 100 days, the penetration in the weld itself was only .004″ in 100 days.

Tests on sodium chloride brines gave relative results much in line with the above but penetration rates somewhat lower.

Acids and Alkalis

The specific and striking property of chromium alloys in corrosion is their resistance to oxidizing attack as typified by the resistance of Inconel and stainless steels to foods and atmospheres. Distinct from this oxidizing attack, acids and alkalis produce corrosion by typical chemical reactions to which chromium alloys are not always resistant. The presence of 80% of nickel is valuable here in furnishing good resistance to both acids and alkalis. The acid resistance of pure nickel is, in most cases, very good, although specific materials such as lead in the manufacture of sulphuric acid, or Monel metal in hot dilute sulphuric in pickling steel may be less attacked. Chromium does not improve the acid resistance of nickel, but neither does it lower it appreciably. Therefore, while the use of Inconel would hardly be justified simply for its resistance to the strong mineral acids, if its use is indicated for other reasons (Fig. 4) its resistance to these or other acids would not be a drawback. In Table V are some typical corrosion rates as determined in test.

Table V. (loss in wt.: milligrams per sq. dm. per day)

Acid	Rate	Conditions
Acetic	11	5%, cold, aerated 16 ft./min. flow (in vinegar)
Hydrochloric	750	5%, cold, aerated 16 " " "
Nitric	1300	5%, cold, aerated 16 " " "
Sulphuric	53	5%, cold, air free 16 " " "
Sulphuric	750	5%, cold, aerated 16 " " "
Sulphuric	1200	5%, hot, aerated 16 " " "

The usual effect of acceleration of corrosion of metals by air and to a lesser extent by heat is notable in the results on sulphuric acid.

Corrosion by caustic alkalis is appreciably more active on the 14% chromium alloy than on pure nickel itself. The difference is plainly noticeable at low concentrations and temperatures. In the high temperatures and concentrations of caustic pots (800° F. and 90% caustic) the chromium nickel alloy is attacked very rapidly.

In dilute solutions and with the presence of sulphur the chromium nickel alloy is better than nickel, but a high iron content increases the corrosion as shown in Fig. 7.

Heat Oxidation

In purely oxidizing atmospheres Inconel has excellent resistance to progressive oxidation at temperatures as high as 2000° F. The resistance to this and other atmospheres is of an order making the alloy useful for high heat apparatus.

The action of sulphur, a constituent of many high temperature atmospheres very destructive to high nickel alloys, is strongly inhibited by the chromium content of Inconel. While the temperature at which Inconel will resist sulphur bearing atmospheres is less than for pure oxidizing atmospheres the resistance compares very favorably with other heat resisting alloys.

In a test in which welded Inconel tubing was heated alternately to 1600° F. and allowed to cool to room temperature, there was no serious deterioration within 2000 hours. This test harmonizes with the practical experience mentioned elsewhere in electric heating units and other places, and is convincing proof that this composition with the favorable structure in-

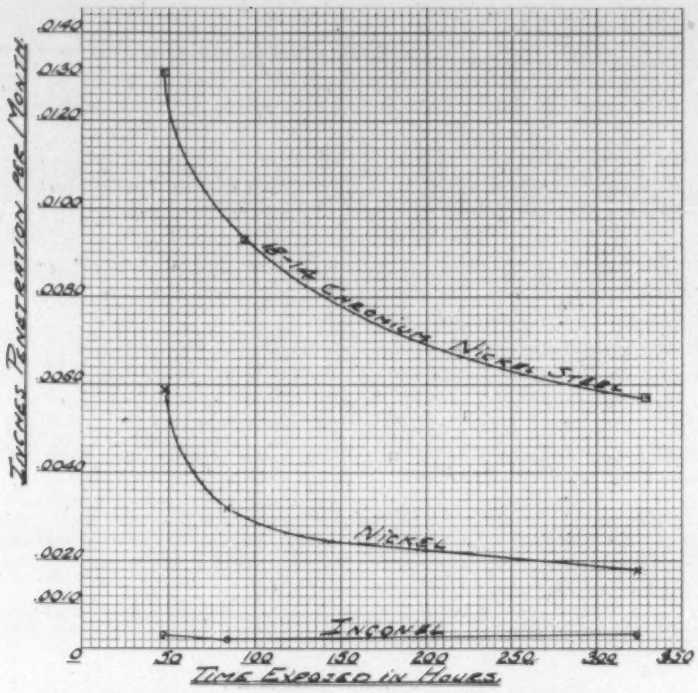
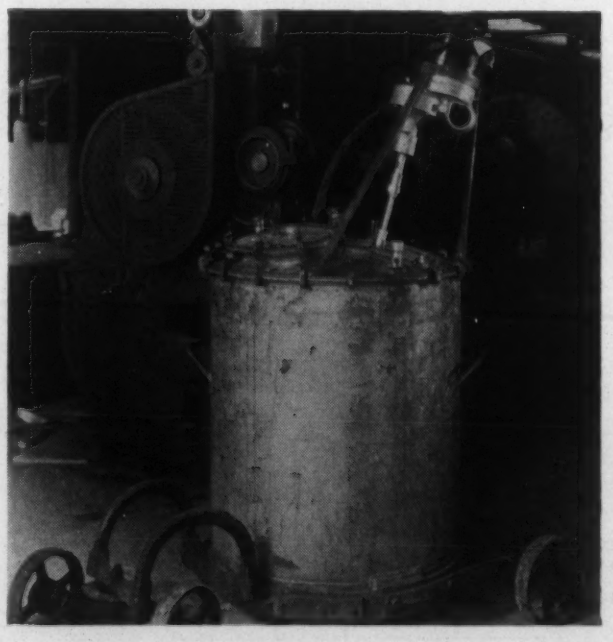


Fig. 7. Corrosion Rate in 50% Sodium Sulphide

duced by rolling or forging is unusually resistant to deterioration at high temperature. This resistance extends to formed and welded assemblies.

Chemical and Electrolytic Corrosion

Nickel alloys are corroded by a combination of oxidation and acid decomposition aided by electrolytic effects. This composition is particularly resistant to oxidizing effects, probably forming an invisible protective film of oxide[7] when oxidizing agents are present and the formation not disturbed by other actions. When this film is present any corrosive action is absent or proceeds at an extremely slow rate. When the film is absent acid replacement can take place but this occurs so slowly and so well distributed that the metal is serviceable for long periods in acids. Pitting of corroding metals is often due to electrolytic concentration effects[7,8] and depends on the maintenance of a cathodic area (usually film covered) together with a chemical condition at the pit which prevents film formation and keeps the bottom of the pit anodic. This high nickel composition does not encourage formation of the anodic chemical condition and it is, therefore, not subject to pitting to the same extent as are high iron alloys. Metal-ion[9] cells are practically absent. Galvanically Inconel is a passive metal. It is rated in the passive stainless group[10] more noble than the brasses and Monel metal and less noble than the precious metals.



Inconel Pressure Kettle for Varnish Manufacturing

[7]U. R. Evans. Corrosion of Metals. Edward Arnold & Co., London, 1926.

[8]R. J. McKay. Corrosion by Electrolyte Concentration Cells. *Industrial & Engineering Chemistry*, Vol. 17, 1925, page 23.

[9]R. J. McKay. Corrosion by Electrolyte Concentration Cells. *Transactions American Electrochemical Society*, Vol. 41, 1922, page 201.

[10]R. Worthington. Notes on Galvanic Corrosion. *The Rudder*, Vol. 49, 1933, page 70.

(Concluded in December issue)

Metallographic Grinding

with Paraffin Impregnated with Abrasives

by R. L. Dowdell* and M. J. Wahll**

Introduction

THE general practice for sample preparation at the University of Minnesota since about 1914 has consisted of dry grinding through French emery paper 000 and occasionally 0000 with a final polish with jeweler's rouge in water on a wheel covered with felt. This practice checks in principle with that reported in recent publications by Vilella[1] and Urban and Schneidewind[2] who have shown clearly that wet cloth wheels with intermediate abrasives are the chief source of pitting especially when large amounts of water are used with the abrasives.

A difficulty with fine grinding on the finer emery papers is that these grades are not uniform in quality and frequently cause considerable scratching. Also, with soft metals the abrasive may be worked into the surface being ground. Vilella and others have applied graphite, soapstone, paraffin, kerosene, etc., to the emery papers in order to keep the soft metals from "loading." Urban and Schneidewind obtained good results by dry polishing on a leather wheel charged with "stainless steel buffing compound," a mixture of alumina and pumice cast in a stearic acid base. Guthrie and Comstock[3] used a paraffined wheel for the intermediate grinding and final polishing stages and abrasives were applied by means of a liquid suspension in a soap solution. The method described here differs from other methods in that we select abrasives of the proper sizes and impregnate them throughout paraffin wheels for the grinding operations.

Grinding Technique

After finishing specimens on a 0 grade of French emery paper or a fine grinding wheel the finer grinding is still done without water on vertical steel disks 8 inches in diameter upon which a mixture of paraffin and abrasive have been allowed to solidify.

Two disks are used: one is 150 mesh carborundum while the other is 400 mesh alundum, both bonded with paraffin. These abrasive paraffin disks are made by melting paraffin and adding sufficient abrasive to make a relatively thick mud. This is stirred well before casting into the mold which is a metal band around the circular steel disk. The abrasive settles rapidly in the liquid paraffin and upon solidification is a compact mass bonded with paraffin while at the top there is a thin layer of nearly pure paraffin. The disks are then dressed with any straight edged tool and if the fine grinding is properly done they will remain dressed for months until worn through completely.

Fig. 1 shows the steel disks which are coated to a thickness of about ½ inch with the abrasive-paraffin mixture. It is believed that stearic acid might serve equally well for the same purpose as paraffin.

The principle of having the mixture of abrasive and paraffin is suitable for many types of grinding where flat surfaces are desired and it appears that almost any size or type of abrasive can be bonded with paraffin for the purpose.

It was first thought that the paraffin might loosen on the smooth steel disks but there has been no tendency to do so. In extremely hot weather the disks are softer than usual but work equally well.

With metals of medium hardness it is possible to apply all pressure possible with the hands without injuring either the disk or the piece being ground; in fact, the higher the grinding pressure the faster the operation. When the disks have the proper flatness and the specimens not too large, only a few minutes are required for each specimen.

Preliminary work has been carried out by applying this same method for the final polishing operation, and indications are that when an abrasive is found which is fine enough it will show results.

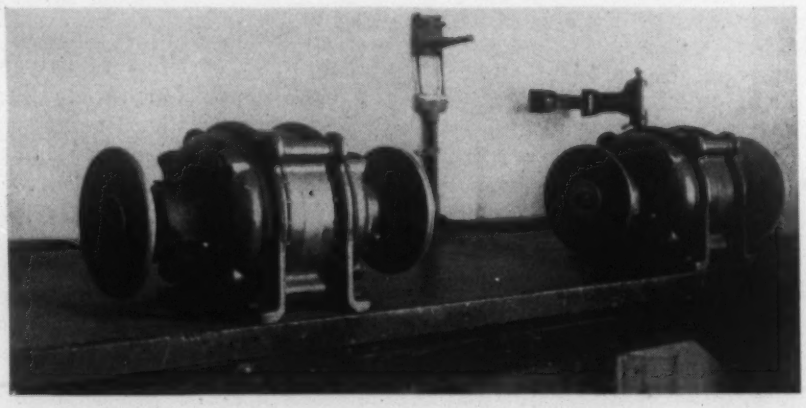


Fig. 1. Abrasive-Paraffin Mixture cast on steel disks for rough polishing. Speed 600 R. P. M.

Fig. 2. Scratches from 000 French Emery Paper. Sample Normalized Steel of 0.70% C. Magnification 50X.

Fig. 3. Scratches from 400 mesh Alumina bonded with paraffin. Sample Normalized Steel of 0.70% C. Magnification 50X.

Fig. 4. Etched Sample of Cast Iron Polished by Simple Automatic Machine. Magnification 100X.

*Professor of Metallography, University of Minnesota, Minneapolis.

**Graduate of Minnesota School of Mines & Metallurgy, Met. E. 1933.

[1]J. R. Vilella. Improved Method of Polishing Metallographic Specimens of Cast Iron. *Metals & Alloys*, Vol. 3, Sept. 1932, pages 205-206.

[2]S. F. Urban & R. Schneidewind. Dry Polishing Will Retain Graphite and Inclusions. *Metal Progress*, Vol. 22, Aug. 1932, pages 38-40.

[3]R. G. Guthrie & J. A. Comstock. Automatic Preparation of Metallographic Samples. *Metals & Alloys*, Vol. 1, 1930, pages 727-730.

The advantages of the abrasive-paraffin disks over French polishing papers are as follows:

1. Abrasive is not worked into surface of soft metals.

2. Exceedingly economical in operation.

3. Specimens do not heat and flow with pressure because of paraffin working as lubricant.

4. Especially fast in operation; aluminum, magnesium, copper, and steel can be polished in about one-third the time formerly required and with less resultant scratches.

Automatic Polishing Apparatus

A machine for the automatic polishing of specimens soft enough to be drilled can be easily made at low cost. With the polishing apparatus shown in Fig. 5, it will be noted that no mounting is required. Sections of cylindrical or rectangular specimens are cut off and simply drilled on the back with a ¼ inch "combined drill and countersink" so as to form a 60° angle. The spindles (¼" diameter) have a 60° pointed end so that they form a bearing with the surface of the conical hole drilled. Specimens will usually rotate continuously with the whole spindle because of the rotation of the polishing disk covered preferably with felt.

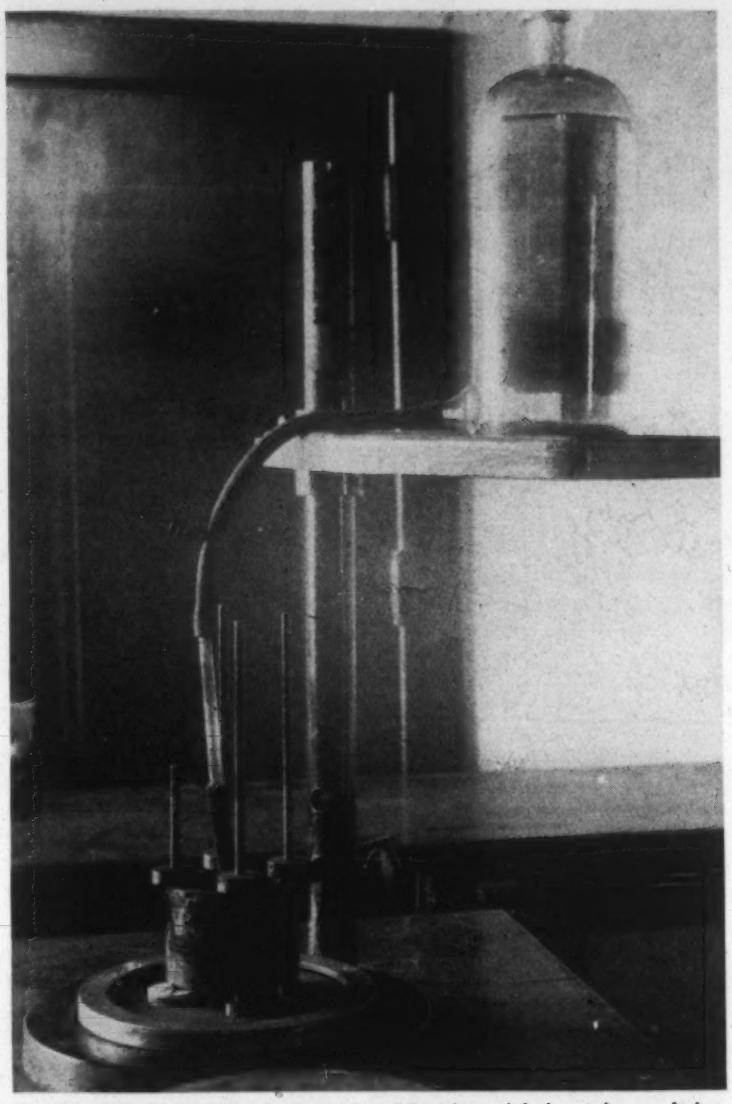


Fig. 5. Simple Automatic Polishing Machine with 4 specimens being polished.

With this apparatus specimens travel in the same concentric circles unless the cross arm is changed from time to time so as to prevent unequal wearing away of the felt.

During polishing a continuous drip of water is applied and a polishing solution of alumina, rouge, etc., added when necessary.

This simple outfit has saved considerable time and produces very good polished surfaces. It is not intended that this simple outfit be compared with modern automatic polishing machines recently brought out; but there are a large number of metallographic laboratories working with restricted budgets which will find a little time spent on the outfit to be well repaid.

If one wishes to examine the extreme edges of specimens it is necessary to protect the edges by some suitable mounting throughout the polishing operation.

Acknowledgment is gladly made to H. P. Nielsen and H. S. Jerabek for aid in this work.

The American Rolling Mill Company, Middletown, Ohio, will manufacture and distribute stainless steel sheets, strips, and plates, according to an announcement by **W. W. Sebald**, Vice-President.

For sometime it has been known that experimental work on stainless steel alloys was in process in Armco plants and that special stainless production equipment was being designed and built.

Armco plants have been producing stainless steel sheets, strips and plates for many months in collaboration with the Rustless Iron Corporation and these products have been used by a number of manufacturers who have coöperated by keeping careful records of the performance under actual production conditions. It is claimed performance under the dies has demonstrated unusual ductility and formability, both of which have resulted in lower tool expense.

Armco stainless steels will be offered in 2 grades, Armco 17 and Armco 18-8. The 17 grade is used for automobile parts, furnace parts, nitric acid and oil refining equipment and oil burner parts. The 18-8, so popular in modern architecture, is widely used for airplane parts, baking, laundry and dairy machinery, beer barrels, hotel, restaurant and kitchen equipment, cooking utensils, soda fountains and counters, etc.

Stocks in all sizes and gages have been built up so the company would be able to serve the trade immediately upon the announcement that it had entered the stainless steel field.

Both production and sales are under the direction of men who have had wide experience with stainless steels. A stainless steel sales department has been created. **J. P. Butterfield**, formerly manager of the Armco Development Department, is in charge. He will be assisted by **E. E. Jones**. Production in the different plants is under the supervision of **Ralph E. Curry** and **W. L. Woodward**, both of whom are Assistants to Vice-Pres. in Charge of Operations. Sales will be handled through Armco's district offices in New York, Philadelphia, Detroit, San Francisco, St. Louis, Seattle, Chicago, Boston, Milwaukee, Pittsburgh, and Middletown.

W. K. Leach, formerly with General Alloys Company of Boston, is now associated with the American Manganese Steel Company as General Manager of the Alloy Division.

Emmett K. Conneely has been appointed Manager of Railroad Sales by Republic Steel Corporation, according to an announcement made by N. J. Clarke, Vice-Pres. in Charge of Sales. Mr. Conneely served in various capacities with the Pittsburgh and Lake Erie Railroad during his early business life, joining the Standard Steel Car Co. during the war. He was later connected with the New York Air Brake Co. as Vice-Pres. and became Vice-Pres. of the Pullman Co. at New York upon that company's acquisition of Standard Steel Car Co. He was subsequently made Vice-Pres. of Standard Steel Car Co. at Chicago. Mr. Conneely will make his headquarters at the Republic general offices in Youngstown, Ohio.

The Youngstown Sheet and Tube Company announces the formation of an Alloy Steel Division. **Harry R. Jones** of Canton, Ohio, formerly President of the United Alloy Steel Corporation, will be in general charge of the Alloy Steel Division. Alloy Steel sales will be in charge of **W. J. MacKenzie**, who will also have charge of Alloy Steel metallurgy. Mr. MacKenzie will be located in Chicago. **John D. Jones** will have charge of sales in the Detroit territory. Mr. Jones was formerly with the United Alloy Steel Corporation and the Central Steel Company.

The Rustless Iron and Steel Corporation, through its subsidiary the Rustless Iron Corporation of America has acquired additional important patent rights. The new Patents have been issued by the United States Patent Office to members of the research staff of Alloy Research Corporation, an affiliated research organization, and assigned to that corporation. One of the inventions covers the manufacture of rustless iron or stainless steel from scrap materials of similar composition. The other patent just issued covers the preparation of important raw materials used in the production of alloys, as rustless iron and stainless steel, before charging into an electric furnace.